EVALUATION OF EXTERNAL FIXATURE IN FRACTURE BOTH BONES LEG- AN EXPERIMENTAL STUDY

THESIS
FOR
MASTER OF SURGERY
(ORTHOPAEDICS)

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C E R T I F I C A T E

This is to certify that the research work entitled "EVALUATION OF EXTERNAL FIXATURE IN FRACTURE BOTH BONES LEG - AN EXPERIMENTAL STUDY", which is being submitted as THESIS for M.S.(Orthopaedics) examination of Bundelkhand University by DR. RAKESH KUMAR SHARMA has been carried out in the Department of Orthopaedics. He has put in the necessary stay in the department as per university regulations.

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C O N T E N T S

INTRODUCTION

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The treatment of long bone fractures has long been a problem, to which, a final answer has yet not been acheived. Fractures of both bones of leg probably the commonest of all fractures, specially pose a great problem in their treatment because of the bone being subcutaneous, thus very susceptible to compounding and having a poor vascularity.

A number of methods for treatment of fractures, particularity of leg, have been devised from time to time. The spectrum of treatment ranges from conservative methods of close reduction with plaster immobilisation, to A.O. and ASIF techniques of internal fixation and highly mechanical external fixation.

The age old, closed treatment is obviously, generally satisfactory in those cases, where the fracture is stable and a good reduction can be achieved, but in cases of unstable fractures it is very difficult to maintain the fractures in reduced position only by the plaster cast and the result is malunion, malposition delayed union or nonunion. In a case of elderly patient and delayed union, patient requires prolonged immobilisation, leading to joint stiffness and remains bed ridden for a longer period with it's own complications.

Plaster immobilisation for a longer period, not only leads to the inevitable problems of joint stiffness, muscle wasting, disuse-osteoporosis, thromboembolic phenomenon, renal calculi and Psychic disturbances; it also shatters the economy of the family as a whole by keeping the patient away from his occupation for a pretty long duration.

Open reduction and internal fixation either with an intramedullary nail or plate, though acheives good apposition of fragments but carries a difinite risk ofinfection, howsoever small. In open fractures specially of tibia the problem is of stabilising the fragments and care of the wound.

According to Burwell (1971) the disadvantages of internal fixation are :-

(1) Delayed Wound healing.
(2) Sepsis.
(3) Loosening of implant, thus loss of rigidity of fixation.
(4) Delayed union and nonunion.
(5) Metal reaction.
(6) Fat embolism and venous thrombosis.

Internal fixtion also disturbs the normal healing process, either by periosteal stripping or blockading the endosteal callus formation. It also hampers the normal healing process by draining the fracture haematoma.

Keeping in view the above disadvantages, various workers have felt a need to evolve a new method of treatment which would eleminate most of the disadvantages of both. The frequency of compounding in leg fractures and their unsatisfactory management by any of these methods also provided an impetus to the search of a newer method of treatment.

A more rigid fixation can be acheived by transfixing Steinmann's pins in the fragments and attaching them to a metallic external fixation device (Hoffman 1957). Thus ensuring a better management of wound in compound fractures and permitting early ambulation, so as to avoid joint stiffness and other complication, without compromising with the rigidity of fixation. The chances of infection are only in a localised area and usually do not spread to the fracture as compared to internal fixation where whole of the medullary canal can get infected.

External fixature also helps in fracture healing by perfect and accurate reduction, firm fixation, maintainance of reduction, provision of compression, early mobilisation and weight bearing.

Over the last few years, external fixation has come up as a potential method for treating fractured long bones, specially those of compound comminuted type. But the devices are not only complicated for the surgeon, cumbersome and costly for the patient (specially in Indian conditions),

they are not easily available also. The experimental trials to evaluate the extent of efficacy of external fixation are also lacking. Hence we have endeavoured to take up this experimental study, to evaluate the efficacy of external fixation in maintaining the fixation of fracture fragments during the period of immobilisation and to evaluate the strength and quality of the union acheived by the external fixation,using a simpler external fixation device, with a low cost and comparing the results with those of the conventional plaster method. Adult rabbits were chosen for the study because of their benign nature, easy availability and adequate size to allow application of external fixator.

REVIEW OF LITERATURE

R E V I E W   O F   L I T E R A T U R E

HISTORICAL ASPECT:

The history of surgery and particularily recognition of fractures together with their treatment dates back perhaps, to the origin of human race. Since, no mode of recording the events existed in those times, there are no data on the methods of treatment practised during that period. Some glimpses, of the knowledge that existed are, however, possible through the various scriptures which came into being subsequently.

The evidences of Egyptologists prove that, many thousands of years ago, broken bones were fixed to the splints, in much the same manner, as the splints are used today.

In India earliest references to the subject of healing of bones are seen in Atharva-Veda (some 2000 years B.C.). Whitney (1962) in his english translation of Atharva Veda quotes as below:

"Grower art thou, The grower; grower of severed bone; make this grow'O' Arundthati"

Later on the Samhitas of Charaka and Sushruta, which were originally written about 1,000 B.C. (Keswani 1967), deal with the diagnosis and treatment of various types of fractures and dislocations.

Sushruta Samhita contains in it, essence of all that was known with regard to surgery and fundamental sciences closely related to this art. The orthopaedic treatment, which was based upon the rich experience of the surgery was rational and, at times, ingenious. Sushruta, The father of surgery, described 6 types of Dislocations and 12 types of fractures, while dealing with the diagnostic considerations (Nidan sthana, second canto of Sushruta Samhita, quoted by Singhal 1977).

The different types of fractures described are:-

1. Karkataka	(Fracture with haematoma)
2. Ashvakarna	(Oblique fracture)
3. Curnita	(Comminuted fracture)
4. Piccita	(Compression fracture)
5. Asthichhallita	(Subperiosteal Haematoma)
6. Kand Bhagna	(Transverse fracture)
7. Majjantargata	(Impacted fracture)
8. Atipatita	(Complete fracture)
9. Vakra	(Green Stick fracture)
10. Chinna	(Incomplete fracture)
11. Patita	(Crack fracture)
12. Sphutita	(Fissured fracture)

The fractures, after a correct diagnosis, were treated among other things, with traction by means of a pully(Chakra). The splinters(Shalya) lost or deeply seated in the organism,

were dextrously handled.

In the treatment of the fractures of lower extremities mention is made of the Kapat-Shayana (Door bed) or a fracture bed consisting of a plank of wood resembling the panel of a door. For fracture of the leg after making the patient lie, 2 pegs were fixed on both sides of knee joints and 2 pegs more fixed on both sides of ankle joint and one peg was fixed against the plantar aspect of foot. Immobilisation of fracture was deemed necessary and was affected by either one of the fourteen types of bandages(Bandha) or by means of bark splints and tying the limbs with bamboo strips. Charaka mentions a bandage Kavalika (tow), so called from medicinal paste which was applied to the affected parts underneath the splints and fixed firmly after setting a fracture (Keswani 1967).

Apart from these references of anicient Indian medicine, no clear concept of fracture treatment, particularly of leg, is available till the middle of 18th century. Hippocrates, was probably, the first to study the effect of musculer spasm on fractures and the uselessness of splintage without relaxing the muscles. The overlapping and shortening produced by it has been a constant headache for surgeons. To overcome these diffiGulties splintage became increasingly popular in the middle of 18th century. There were attempts to produce sophisticated splints as shown in Savigny's instrument catalogue of 1798(quoted by

Gibson 1976). Crammer wire was popular too and the first illustration of such a wire mesh is found in 1845.

Amesbury, who practised in the first half of Ninteenth century wrote several treatises on fracture and deformities, in one of which he described a splint for treating non union in the lower leg (Gibson 1976).

Since then a number of treatments of fractures, particularly of leg have been devised from time to time.

The common methods of treating all types of fracture leg can be divided into following heads:-

(1) Conservative method-closed reduction followed by plaster immobilisation.

(2) Open reduction and internal fixation with or without A O or ASIF Techniques.

(3) Reduction followed by immobilisation by external fixation.

<u>CONSERVATIVE AND OPEN METHODS</u>:

Until recently, closed reduction and plaster immobilisation has been the most accepted treatment for fracture leg by various workers. But the consistant complications like joint stiffness, muscle wasting, disuse osteophrosis, thromboembolic phenomenon, renal calculi and hypostatic pneumonia, which are invariably associated with prolonged immobilisation, apart from the problems of malunion, malposition delayed union and non union,

have led the orthopaedic surgeons to use newer methods which are comparatively free from these problems.

Oskar Lindon (1938), observed in a study of 52 cases, treated by conventional method, the average healing time of tibial shaft fractures to be 22.3 weeks with period of stay in hospital for 72 days. The average shortening was 1-2 cm.. 5° to 10° of valgus in 20 cases (38.4 %) and varus in 13 cases (25 %) and recurvatum in 19 cases(29.2 %) was reported.

Robert Funstein (1945), reviewed 149 cases of fracture of both bones leg and found average healing time of 11.2 weeks for clinical union and 30.4 weeks for radiological union. Types of fracture made practically no difference in the rate of healing. Nicoll (1964) observed healing time of 16 weeks, average being 12 - 20 weeks in tibial fractures treated with plaster. 25 % cases had foot and ankle stiffness.

Edwards (1965), published a series of 492 tibial shaft fractures treated by above knee plaster cast. The result after one year followup were classed as good, fair and poor on the basis of pain, work capacity, limp, participations in sports, knee, ankle and foot motion and swelling over the lower leg. Longitudinal fractures showed 83 % good and 7 % fair results, while closed transverse fractures showed 95 % as good or fair and 5 % as poor results. Healing time was 9 months in closed transverse fracture and 14 months in open transverse fracture.

The complications observed were skin necrosis, osteomyelitis and malunion in 4 cases (7.2 %).

Slatis (1967) studied 198 tibial fractures, treated conservatively, with 60 % of lower 1/3 and 40 % of middle 1/3, out of which 24 % were compound fractures. Average healing time was 19.8 weeks. 90 % cases could resume work by 12 months. Closed fractures with little displacement and no comminution united well irrespective of the site of fracture.

Concerned with the problems of osteoporosis, joint stiffness, muscle wasting, post plaster oedema, and prolong period for which patient is kept away from his occupation, some workers went for initial open reduction and internal fixation, and compared the results with those of conservative treatment.

MC Laughlin & Harrison (1949), studied 200 consecutive fractures of tibia treated by internal fixation and observed the complications which were :-

(i) Metal reaction.

(ii) Deep wound infection in 5 % cases. While the advantages observed were as under :-

1. Maintenance of length and axis of the long bones even in the presence of comminution.

2. Early acheivement of good range of joint movements.

They reported that 90 % patients with fracture of tibia and femur had full range of knee and ankle motion after open reduction.

Lottes (1952), while evaluating the results of 176 fractures of tibia, observed that weight bearing at the end of 6 months of treatment was seen in 74 %, 16 % and 6 % patients

patients treated by nailing, plating and plaster immobilisation respectively. Incidence of non union was 23.7 % with plating and 10 % with conservative method of treatment, while in none treated by nailing. Other complications, which were mainly seen after plaster treatment were, shortening, rotation and thrombophlebitis.

Blocky (1956), emphasised more on the advantages of rigid fixation by doing internal fixation in fractures. In his opinion plaster immobilisation can never give rigid support, no matter, how well the plaster is given and also that plaster can never give that degree of fixation which is essential for union in ideal circumstances.

Solheim (1960), studied 800 tibial fractures treated by closed reduction and plaster cast, and open reduction and internal fixation. Healing time was least in patients treated by closed reduction and plaster. Compound fractures took maximum time to unite, while transverse fractures took least time to unite. The incidence of knee stiffness was 23 % when period of immobilisation was more than 16 weeks, while it was 8 % when it was less than 16 weeks. Overall incidence of swelling was 8 %.

Michael Alms (1962), reviewed 200 tibial fractures treated by above knee plaster with absence from work for 22 weeks, while on the other hand, in fractures treated c̄ intramedullary nailing the average time of absence from work was 13 weeks.

Despite the obvious advantages of good reduction and early mobilisation internal fixation carries a definite risk

of infection which can range from a mild degree to involvement of whole of the diaphysis. According to Burwell (1971), the disadvantages of internal fixation are :-

1. Delayed wound healing.
2. Sepsis.
3. Loosening of implant, thus loss of rigid fixation.
4. Delayed union and nonunion.
5. Metal reactions.
6. Fat embolism and venous thrombosis.

This is obvious that while treating a fracture both bones leg, both the conservative and internal fixation methods have their own advantages and disadvantages and some times the disadvantages outweighing the advantages. At this stage treatment by applying an external fixation seems to eleminate most of the disadvantages of both the plaster immobilisation and internal fixation and incorporates the advantages of both the methods.

EXTERNAL FIXATION:

External fixation refers to a method of immobilisation of fractures which employs transfixing pins in bone, attached to a rigid external metal frame or incorporated in plaster.

The first external fixation device, for the treatment of fractures, was described by Malgaigne in 1851, who employed claw like external fixation device for the first time(Ruskin 1980).

In 1897, Clayton Parkhill, an American surgeon, inserted screws from cortex to cortex and then connected them with an

external clamp, in treating difficult fractures of femur. This apparatus became known as Parkhill bone clamp.

In 1904 Codovilla employed the principles of pins in leg-lengthening operations, he connected the pins with external bars without the use of plaster.

After the advent of Steinmann pin, in 1907, by Steinmann (Steinmann 1907) various interpretations of it's adoption, specially with regard to external fixation of the pins with plaster or mechanical devices were published by many workers.

Lambotte (1907), used an external fixation device similar to present design. He used percutaneous half pin with a rigid external frame in cases of femur and other long bone fractures.

Bohler's contribution during this period was outstanding. His use of a simple reduction fracture frame and screw traction apparatus, in conjunction with pins or wires introduced a new era in accepted fracture treatments. His persistent efforts and successes were cheifly responsible for the gradual elimination of pin phobia, held then by many surgeons.

Freeman (1919), published an article advocating the use of external fixation in the treatment of fractures. He pointed out and emphasised the advantages of this method. But the method never became popular because of through and through pinning required. Lamare described angular pins placed through the outer and inner cortices only and bridged them in units by means of metal bars. Thus, he opened the approach to an external mechanical

method of treating fractures, which could be applied to one aspect of the limb only, thereby eliminating the objectionable through and through pinning and plaster.

In 1931, Stader, while working in the field of veterinary surgery, was worried over the inadequacy of the methods in use for treating the fracture shaft of long bones in dogs. Plaster was not tolerated by the animals. They frequently destroyed it by constant biting and tearing, or the plaster was disintegrated by constant soiling with excreta. Traction and counter traction in a modified Thomas splint had been used extensively, but the degree of fixation obtained was usually insufficient and pressure necrosis from the rings often defeated it's continuous use. Stader then used two half pin units in each fragment, connected by an adjustable metal bar. Thus, he could usually acheive anatomical reduction and it did not seem to annoy the animal and was well tolerated by them until union of fracture had occured. Till May 42 he had treated over 1200 fractures in dogs, with the results obtained being uniformally good and far superior to the older methods of treatment.

In 1934 Roger Anderson devised an apparatus, a fracture table 20" long with many adjustments, also called as fracture robot. After reduction of fracture he used to incorporate the transfixing pins in the plaster cast. He allowed the patient for crutch walking on second day, but body weight bearing was not allowed for the first few weeks.

In compound fracture with extensive soft tissue injury the leg was left completely exposed in the splint, for as many weeks as necessary, while the wound and the fracture were receiving simultaneous repair.

Lewis and Breidenboch (1942), had the opportunity of seeing the Stader splint applied to a police dog for fracture shaft femur. They were very impressed by the ease of application, the prompt and accurate reduction obtained and the simplicity of the instrument. They decided to have a larger model of splint for use in human beings.

In October 1937, the first patient named W.W. was treated by this method for fracture of both bones leg in fourth division of Bellevue hospital, New York. Patient was able to bear the weight on injured limb in two weeks. During the period between 1937 and 1942, a total of 20 patients were treated by this method with uniformally good results, except in 3 patients where infection around pins occured, but promptly subsided after removal of pins. The splint was kept in place until bony union had occured, which varied from 8 to 16 weeks.

From 1933 - 38, 289 leg fractures were treated by Griswold and Holmes by pins incorporated in plaster. The results obtained were good.

Shaar and Kreus used Stader splint in 157 cases of various types of fractures. They analysed 84 cases of simple fractures and 21 compound fractures of tibia and fibula. No

pintract infection was reported. None of the cases passed in to nonunion. Knee and ankle movements restored normally and no physical therapy was required. They advocated the Stader splint as an ideal device for treatment of compound and comminuted fractures of tibia.

Maset, in 1943, after his observations, enlisted the advantages of this method as follows:-

1. It presented the more perfect and accurate method for obtaining reduction.
2. It provided firm fixation.
3. It avoided distraction.
4. Permitted early ambulation.
5. It was valuable in cases of compound fractures where dressing, skin grafting and procedures like muscle mobilisation and bone grafting can be carried out without disturbing the fragments.

During the period between 1942 and 1949 a total of 237 Tibial fractures were treated with this method by Maden. He reported end results in 206 of them. In most cases he used 2 through and 2 half pins. An extra half pin was added to prevent side slipping. If the general condition of the patient was good, ambulation on crutches was started on next day of fixation. Full weight bearing was deferred till the evidences of clinical and radiological union. The average period for union of simple fracture was 16 and half weeks, and for compound fractures 22 - 34 weeks.

Five per cent of the patients developed minor irritation around pintract. A few patients had definite infection but without involvement of bone. Four patients showed small sequestra around the pin sites. The wound healed following their removal. One patient had low grade infection in tibia with persistent drainage. One patient had a pin clamp broken after one month. The fracture was displaced badly and required open reduction, bone grafting and repining. One patient had sloughing of paroneal group of muscles with lateral popliteal nerve involvement, but this improved with time. Two cases of simple fracture and four cases of compound comminuted fractures with bone loos passed into non union, which were later treated by bone grafting.

By1950's, however, external fixation had fallen into disrepute because of high rate of complications reported to accompany the use of device with poor adjustability and inadequate rigidity(Anderson Roger, 1943; Davis, 1943; Naden, 1949), however these complications could be attributed to the poor quality of the external fixator itself. Although success was reported, pintract infection and delayed union fequently occured.

In 1950, a retrospective study was conducted by the committee on fracture and traumatic surgery of the American's academy of orthopaedic surgeions, to evaluate the external fixation method of treatment.Out of 369, 287 surgeons felt that this method had not advantage over other methods. The disadvantages listed were soft tissue infection at fracture site, ring sequestra and osteomyelitis followed by nonunion, mechanical difficulty,

pain, conversion of simple fracture into compound fracture and difficulty in obtaining and maintaining reduction. Pintract infection was the chief cause of discontinuing the use of external fixation.

External fixation was advocated by Charnley in 1944 for compression arthrodesis of knee. Hoffman in 1938 developed a 4 poster double frame external fixation device which was later modified by Vidal in 1973 and is still one of the latest available.

Vincent et al. (1969), presented a five year followup of 75 human lower third tibial shaft fractures treated by percutaneous semi-rigid fixation. They inserted four pins, one each through calcaneum, tibial tubercle, and above and below the fracture site. Pins were incorporated in a short leg plaster cast. In these patients immediate weight bearing was initiated. All the fractures united with an average of ten and half weeks without any considerable complication.

Besides the attempts to incorporate the pins in the plaster, some surgeions used dental methyl methacrylate to fix the transfixing pins with the vertical side bars.

Increasing incidence of compound fractures of leg due to increasing vehicular accidents and their unsatisfactory treatment by the conventional plaster method or internal fixation has been the most probable cause of reviving the orthopaedic surgeion's interest towards the external fixation method of treatment recently.

Karlstrom treated from 1970 to 1973, 28 severe open tibial fractures and experienced excellent or good results in 17 patients. Average time for full weight bearing without support being 7.9 months.

Burke et al. (1977), reviewed 28 patients with a total of 26 fractures of long bones and 6 pelvic fractures treated with the Hoffman external fixation apparatus. All the extremity fractures were compound with varying degree of soft tissue injury including seven with neurovascular complications. In these patients a total of 54 secondary procedures consisting of debridement, skin grafting and bone grafting were performed with the apparatus in place. They concluded that the device offered advantages which far outweighed the objections to its use in the management of compound fractures of long bones and infected nonunions.

Edwards (1979), reported the study of 44 open tibial fractures in patients of multiple trauma. 73 % of the cases had bone loss or major comminution, 55 % had soft tissue loss. After initial debridement a double frame Hoffman apparatus was applied and fracture reduced. The wound was packed, left open and limb was suspended from an overhead beam. Once the wound was healed the external fixation was removed and the weight bearing cast was applied.

In this series the results using external fixation were clearly better than those treated with other alternative methods. Fifty seven per cent of the cases achieved primary bone union with

good tissue coverage and had no related complications. Bone grafting was required in 39 percent cases, muscle flaps in 30 percent and skin grafts in 48 percent. Initial union was evident at four months and complete at seven and half months. 23 percent of the tibia developed osteomyelitis and 30 percent of the cases had at least one pintract infection which cleared after pin removal. A few cases developed ring sequestra requiring ccurettage. Nevertheless pintract infection remained a common problem even with enlightened Hoffman apparatus.

Vidal et al. (1979), also presented few examples of open fractures with loss of bone substance. They considered Hoffman's device to be indispensable in the treatment of fractures with loss of bone substance. It permitted easy surveillance of wound, was completely versatile and sufficiently stable. This method, judiciously executed has enabled them to save numerous limbs, which would have otherwise been amputated.

Lawyer and Lubber (1980), used the four poster double frame developed by Hoffman in 1938 and modified by Vidal (1973). According to them the traditional problems in the treatment of fracture long bones include:-

(i) Devascularization either traumatic or iatrogenic.

(ii) Instability leading to loss of reduction.

(iii) Bone loss or distraction.

(iv) Infection.

Properly applied external fixation can minimize and in most cases can overcome these problems.

In their own 34 complex tibial fractures, otherwise considered to have a poor prognosis, they acheived anatomical reduction in 25 fractures, while, in most of the cases closed reduction was tried, compression by Hoffman apparatus could only be applied in transverse fractures. In oblique fractures cortical lag screw across the fracture site was used. In severely comminuted fractures or with extensive bone loss, apparatus was used to maintain the length of limbs till bone grafting was done. The average time of union was 5.8 months which appeared to be directly proportional to the accuracy of reduction. 25 fractures which could be anatomically reduced and compression was applied, united in an average time of 5.1 months. In compound fractures, union time was delayed to 8.8 months as compared to 5.3 months taken by closed fractures.

No incidence of chronic osteomyelitis was observed resulting from pintract, However a few cases of pin tract infection were observed, which responded to conservative means. Four patients had minor angulation of less than 15° in aneroposterior plane. In six cases painful fibular nonunion occured which was later treated by plating and/or bone grafting. In no patient tibial nonunion was observed. None of them had clinically significant limitation of knee or ankle movements.

In this series, primary bone healing was achieved when the fracture was anatomically reduced and movements at fracture site were minimum. This was shown by clinical stability in two to three months without evidence of visible callus

on roentgenogram.

Lawyer and Lubber, advocated the philosophy of anatomical rigid fixation of fractures, which they believed, was possible by external fixation with inflicting minimal vascular damage.

Recently Edge and Denham, used Portsmouth external fixation device to treat 38 complicated tibial fractures. 90 % of their patients acheived union. 16 of the patients developed mild pin tract infection. None of their patients developed joint stiffness.

Though most often used for treating fracture legs, the external fixation has been tried in the treatment of other long bone fractures, as well as the pelvic fractures.

Kuderna (1977), and Seligson (1978), used it for compound comminuted fractures of femur and pelvic bones and found good results. Kamhin et al. (1978), and Burney et al. (1979), used external fixation devices for treating simple and complicated fractures of humerus.

EXPERIMENTAL STUDIES:

Although experimental studies to study the fracture healing by use of an external fixator device are very few, the literature abounds with reports studying the effect of familiar types of treatments of fractured limb.

However, as outlined by Mazet in 1943, the following advantages of external fixation are also reported to have a

favourable effect on fracture healing.

(i) Perfect and accurate reduction.

(ii) Firm fixation and maintenance of reduction.

(iii) Provision for compression.

(iv) Avoidence of distraction.

(v) Early mobilisation and weight bearing.

(vi) Rapid soft tissue healing in cases of compound fractures.

According to Anderson (1965), there are 3 areas of osteogenic potential in healing of any fracture.

(i) The periosteal reaction.

(ii) Endosteal or Medullary callus.

(iii) Fracture haematoma.

The cortical fracture ends are a fourth possible area of osteogenic potential.

In the fractures, treated with inadequate fixation or those with marked overriding and angulation of fragments, the periosteal reaction and endosteal callus can be of little help in their healing. Union in these fractures is almost entirely by massive formation of cartilage within organising fracture haematoma and gradual conversion of this cartilage to bone by enchondral ossification.

Fractures treated with medullary nails must unite by peripheral callus because the nail blocks the endosteal callus formation. Union is therefore entirely peripheral and

takes place bybone formation in fracture haematóma, bridging the gap between the periosteal reaction of two fragments. There is little doubt that the insertion of medullary nail is basically unphysiological because it destroys the medullary blood supply and a large part of blood supply of cortex, and prevents formation of endosteal callus. Delayed union and non-unions are the rule when the nail was inserted loosely or became loose (Anderson 1965).

On the other hand the plate and screw fixation produces less damage to the medullary and cortical blood supply. The peripheral bone formation from periosteum and bone formation in fracture haemotoma are not prominent. While some authors have deemed periosteal callus more important (Phemister 1935, Gallie 1919, Ham and Harris 1956, Nilsonne 1961, Mclean and Urist 1961), others,have thought that endosteal callus formation is more important for fracture healing (Enne King 1948, Anderson 1965, Rhinlander 1974).

There is no such problem with external fixation at it does not hamper with either medullary vasculer system or the normal effective blood flow of the cortex. It also does not drain the fracture haematoma which is responsible for primary bone union.

Rhinelander in 1968, while studying the healing by microangiography in dogs, observed that in cases of stable reduction of fragments, the medullary circulation, crossed the fracture gap within at least 3 weeks but when the reduction was unstable, the cheif medullary arteries remained blocked at the fracture fibrocartilage for a longer period. He also reported that when the fracture fragments were stable, osseous callus at 3 weeks had united the portion of living cortex across the fracture line.

According to Verma and Mehta (1967), perhaps continued mobility, following loose fixation, is responsible for prolonged relative or complete avascularity at the fracture site, by hampering with the ingrowth of capillaries, which does not take place, till the mobility is reduced by formation of primary fibrocartilagenous callus, favoured due to low oxygen tension caused by relative ischaemia. When the fracture is rigidly immobilised the ingrowth of capillaries can take place more rapidly and hence there is direct bone formation.

Verma and Kumar (1973), studied in an experimental study, fracture healing under different types of fixation taking rabbits as experimental animal. They divided 24 animals in to 4 groups of 6 animals each. After producing a fracture in the midshaft of tibia manually, every group was treated with a different type of immobilisation.

In the first group of animals, treated by a long leg plaster cast, healing of fracture was acheived in 4 weeks time. Criteria of union being radiological as well as clinical. The callus was well consolidated by 4 weeks. Measuring the tensile strength of the callus they observed a rapid increase in tensile strength after 4 weeks. The tensile strength of callus at 2 weeks was 6.4 kg., which reached to a maximum of 12 kg. at the end of 6 weeks. Reductions of fractures were more or less satisfactory, but anatomical reduction was exception. No primary union was acheived at the fracture site.

In next group treated by unstable intramedullary fixation by a loose Kirschner wire, thus allowing movements at fracture site, though the reduction acheived was almost anatomical, clinical and radiological union occured after 5 weeks with a large spindle shaped peripheral callus which showed poor consolidation. The fracture line remained visible radiologically till the end of 6th weeks. The maximum tensile strength of the callus obtained was 7 kgs. at the end of 6 wks.

The animals treated with intramedullary stable fixation showed clinical and radiological union after 4 weeks, with a minimal of well consolidated peripheral callus. Fracture line underwent a gradual fading and was not visible radiologically from 4th weeks onwards. Tensile strength of the callus which was 6 kg at the end of 2 weeks, Reached to a maximum of

9.5 kg. at the end of 6 weeks. The tensile strength showed a rapid increase after 3 weeks. Histologically minimal of cartilage was found from the end of 5th weeks. Similar are the observations of Anderson (1965), Varma and Mehta(1967), and Lettin (1968).

Lane (1979), and Li (1979) studying effect of immobilisation on the healing fractured tibiae of rats observed maximum callus size in mobilized tibiae at the 4th week. Fracture lost its radioluscency by 7 week. In this model the firmly fixed and immobilised limbs developed a very sparse external callus, with negligible amount of cartilage. Moreover the bone healed by direct membraneus bone formation.

Compression over the fracture site also helps in promoting bone union. (Basset 1962, Anderson 1965, Simmons 1980). Compression over the fracture site can be very effectively provided by means of external fixator device without disturbing either the periosteal or medullary circulation and without draining the fracture haematoma.

Basset's (1962), work on tissue culture has shown that premitive mesenchymal cells exposed to high oxygen concentration and tension develop into osteoblasts. Low oxygen tension or distraction produced fibroblasts.

Anderson (1965), holds that compression appears

to be beneficial in cortical bone fracture because it increases the rigidity of fixation by impacting the bone ends and the space between bone ends, which must be bridged by new bone, is narrowed. He acheived 100 % union, of experimental osteotomies, in aminals sacrifised 6 weeks after the operation, with direct cortical healing of osteotomies.

Schenk and Willengger (1964), acheived healing of osteotomies in dogs fixed rigidly with compression plate without any externally demonstrable callus. Verma and Mehta (1967), in their experimental studies of fracture healing with different types of fixation observed, that with a stable fixation, healing occured easily by a direct intra membraneous new bone formation with little peripheral callus. Where as with loose fixation there is greater amount of periapheral callus formed by enchondral new bone formation.

Hicks (1960), pointed out that, the amount of callus varies with the degree of rigidity involved. Similar were the observations of Hutzschenreuter (1969).

Strength of callus has been shown to be inversely proportional to the size of callus (Piekarski 1969). He explained the low strength of the callus having a large cross section by the greater porosity.

Experiments of Rezaian (1971), further support the observation of the previously reported studies, regarding

the effect of absolute reduction, firm fixation and compression over the fracture of long bone by external fixation. He observed that it provided absolue rigid fixation and accelarated the process of fracture healing.

Studies on the effect of external fixation over the fracture healing and how exactly it promotes the healing are rather lacking and a further research in the field is necessary.

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MATERIAL AND METHOD

M A T E R I A L   A N D   M E T H O D

The present study was conducted at the experimental research laboratory of M.L.B. Medical College, Jhansi.

Adult rabbits, of genus Oryctologus, were chosen for the experiments. Rabbits were selected from weight group ranging between 1 kg. and 1.3 kg. All the experimental animals were fed on a standard diet during the whole period of experiment.

COMPOSITE PLAN OF STUDY

Experiments were performed on ninety animals divided in two groups of 45 each, after producing a closed fracture in mid shaft of right tibia manually.

Group I - Fractured limb immobilised by a long leg plaster cast after reduction.

Group II- Immobilisation done by external fixation device after reduction and final adjustment of reduction done by adjusting the external fixator.

From each group nine animals were sacrificed every week, starting from the end of second week up to the end of six week. Every animal was subjected to clinical, macroscopic and radiological examination. Finally, the animals sacrificed every week, were subdivided in groups of three, for the purpose of testing the

mechanical strength of callus, as follows:-

(a) Tensile strength 3 specimen

(b) Compression strength 3 specimen

(c) Angulatory strength 3 specimen

<u>Group A or B</u>

Period	No. of Animals Sacrificed	Methods of Study	
2 week	9	Clinical 9	
		Radiological 9	
		Mechanical test.	(a) Tensile Strength -3 (b) Compression Strength-3 (c) Angulatory Strength -3
3 week	9	Clinical 9	
		Radiological 9	
		Mechanical test	(a) Tensile Strength -3 (b) Compression Strength-3 (c) Angulatory Strength -3
4 week	9	Clinical 9	
		Radiological 9	
		Mechanical test	(a) Tensile Strength -3 (b) Compression Strength-3 (c) Angulatory Strength-3
5 week	9	Clinical 9	
		Radiological 9	
		Mechanical test	(a) Tensile Strength -3 (b) Compression Strength-3 (c) Angulatory Strength-3

6 week	9	Clinical	9
		Radiological	9
		Mechanical Tests	(a) Tensile Strength -3 (b) Compression Strength -3 (c) Angulatory Strength -3

Details of External Fixator

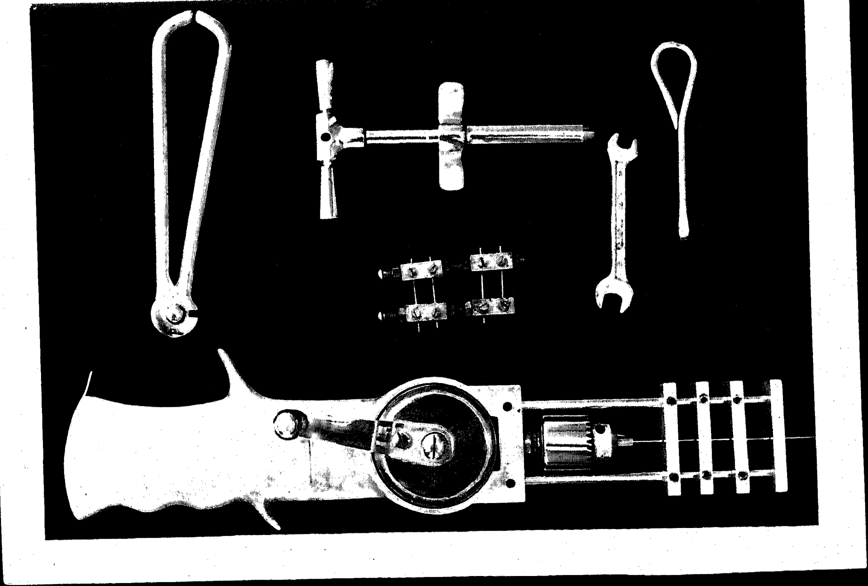
Theexternal fixator device, used in this study, was fabricated by us and comprised of two threaded bars - one medial and one lateral. Each bar has two overrding sleeves, with an internal diameter corresponding to the external diameter of the bars, so as to allow free to and fro movement of the sleeve over the bar but without any - play. Through horizontal holes in these sleeves, the transfixing Kirschner wires are held firmly with the help of vertical grab screws. Each sleeve can be fixed at any desired point by two nuts on each side of the sleeve. Compression or distraction of desired amount can be applied by properly tightening or loosening these nuts and thus forcing the sleeves to move in desired direction.

Prior to the surgery whole of the external fixator, Kirschner wires and other instruments were sterlised by autoclaving along with linen and dressing material etc.

Details of Study

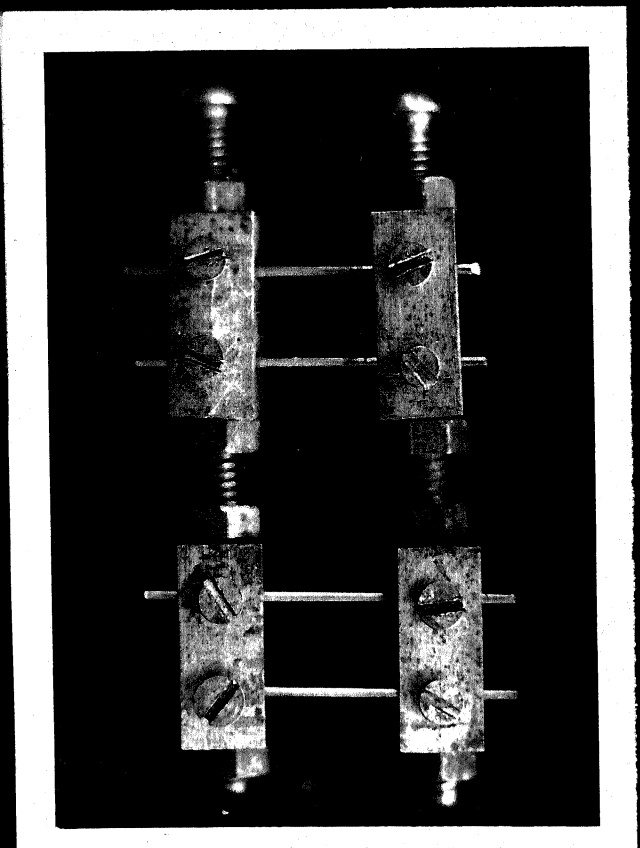
(1) Fracturing the bone:

The animals were anaesthetised by intravenous Nembutol (25 mg/kg body weight) and the mid shaft of the right tibia was fractured manually by applying angulatory force. The fracture was completely displaced.

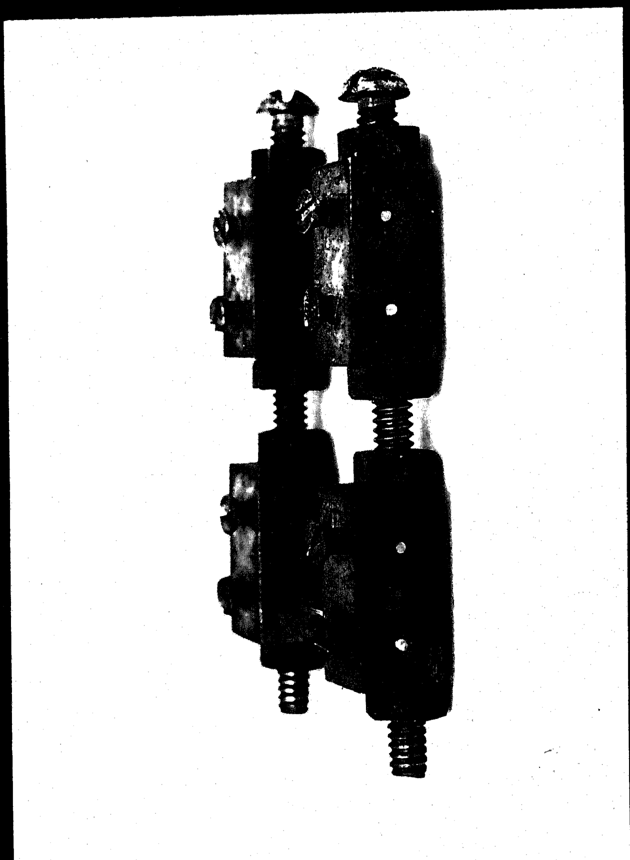


Basic instruments needed for application of external fixator.

External fixator



Front view



Side view

(2) Immobilisation by Plaster:

The two fragments of tibia were reduced manually and were held in aligment as far as possible. Long leg plaster cast using commercially available plaster of paris Gypsona bandages was applied over a thin layer of cotton wool padding.

(3) Immobilisation by External fixator:

a. The fractured leg was shaved. Drapping was done in sterile sheets, after painting with savalon and spirit.

b. The fracture was reduced manually and then with the help of K wire hand drill, a K wire was inserted transversly in the proximal fragment through both the cortices. Another K wire was inserted at a distance of approximately 1 cm. (measured exactly by the distance of holes in the sleeve of external fixator). Care was taken to ensure that both the transfixing wires are parallel to each other and at a horizontal level. K wires used were of two sizes - .036 and .045.

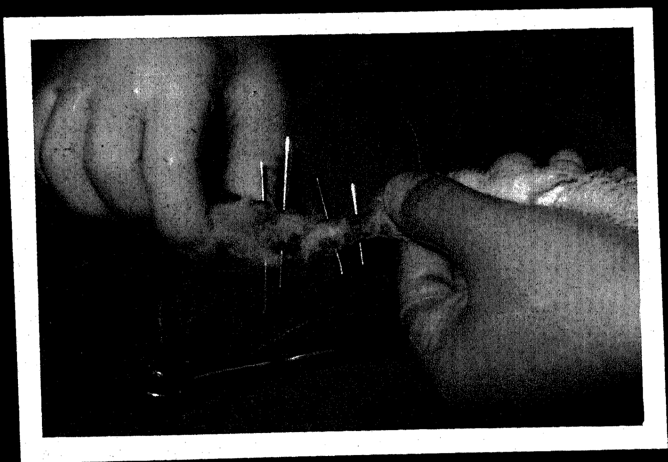
c. Similarly two Kirschner wires were passed through the distal fragment.

d. Both the lateral and medial bars of the external fixator were applied to these K wires, which were passed through the horizontal holes in the sleeves, moving on both the bars. The bars were kept as close to the leg as possible. The K wires were tightened by the grab screw on the sleeves.

e. Necessary adjustments were made with the help of

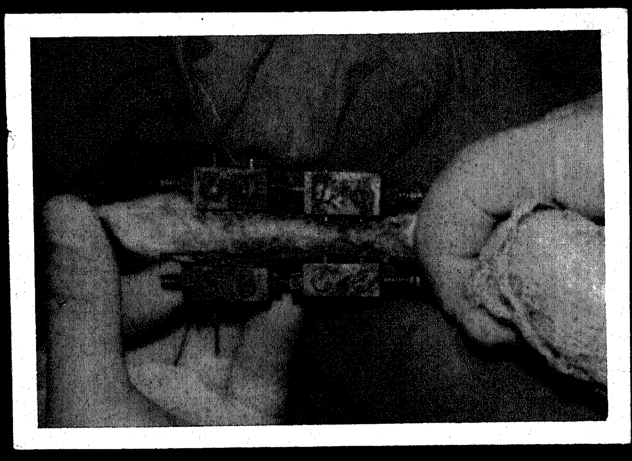
Introduction of K wire in the proximal fragment after fracturing the leg.

Introduction of second K wire.

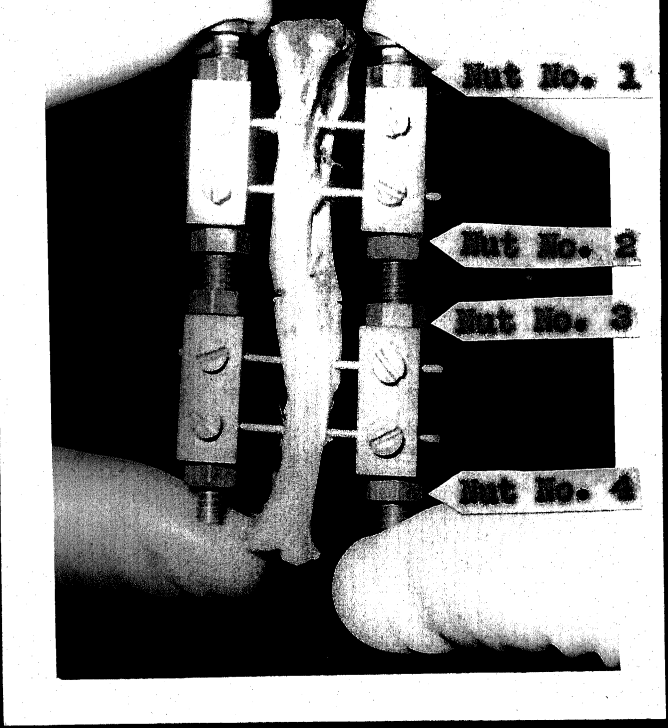


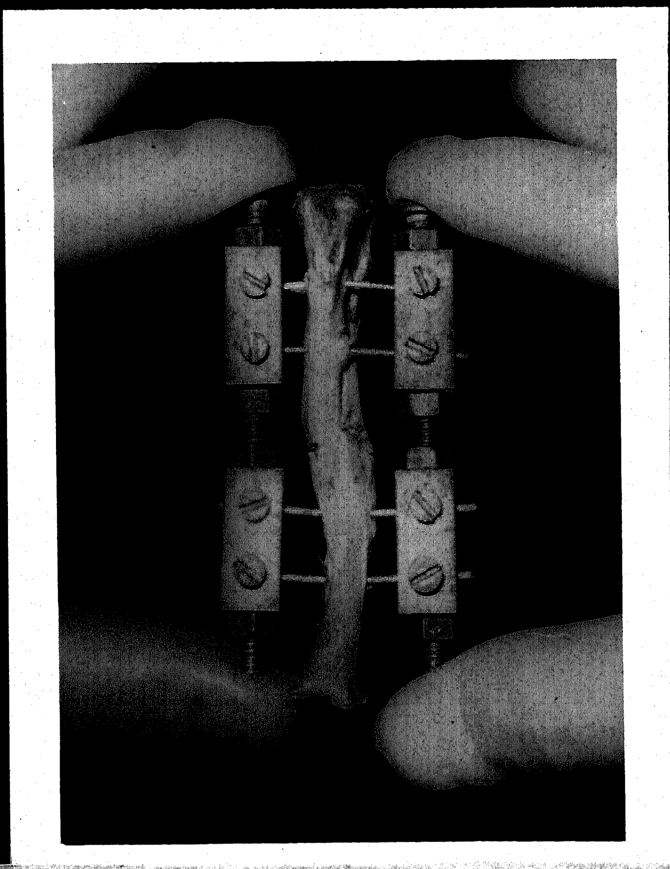
K wire introduced in both

Application of external fixator and manipulation of fragments to acheive reduction.



External fixation in place after acheiving reduction.





Showing application of compression at the fracture site. Note the bending of K wires.

screws and nuts to acheive the maximum possible reduction of fragments clinically. While attempting reduction, nut No. 2 and 3 were tightened away from the fracture site while nut No. 1 and 4 were loosened. Once the reduction had been achieved, compre-ssion at the fracture site was given by tightening the No. 1 and 4 nuts on both sides of the leg towards the fracture site. Compression applied was such, as to cause slight bending of the transfixing K wires with concavity towards fracture site.

(4) Postoperative care:

In the animals which were immobilised by a long leg plaster cast, a routine check up of toes was made. In a few animals initially there was swelling for one to two days which subsided after slitting the plaster throughout its length. Slitted plasters were repaired just after the slitting, so that the position of fragments was not disturbed. No antibiotic was rout-inely used postoperatively in any of the groups. However a few cases in the Group B who showed signs of pintract infection later on, were put on intramuscular antibiotic (oxytetracycline 100 mg/day) and the response noted.

X-Rays of the fractured limbs were taken (both A.P. and lateral or oblique views) immediately after the reduction and immobilisation in both the groups, and the state of reduction, degree of displacement, angulation and overriding at the fracture site were noted.

<u>Methods of Study:</u>

The study was done under the following heads:-

1. Clinical Examination.
2. Radiological Examination.
3. Gross or Macroscopic Examination.
4. Mechanical Strength of callus.
   (a) Tensile Strength.
   (b) Strength on applying compression force.
   (c) Strength on applying Angulatory force.

1. <u>Clinical Examination:</u>

Animals were regularily assessed clinically throughout the period of study. Behaviour of the animal and use of the fractured limb was observed. Complications like loosening and tightening of plaster, circulatory impairment, oedema, intolerence to plaster, signs of infections were noted. External fixation device was also checked regularily for any loosening of screw or transfixing K wires. Range of movement at knee joint of the treated side was recorded by a goniometer before sacrifising the animal.

(2) <u>Macroscopic Examination:</u>

The animal was killed by a direct blow on the neck. The plaster or the external fixation device was carefully removed and the length of the limb was measured. The bone was freed from all the soft tissues meticulously, so as not to

disturb the position of the fragments and a naked eye examination was done. Following points were noted:

(i) Presence of external callus-size and consistency.

(ii) Presence or absence of mobility at fracture site.

(iii) Displacement and angulation of fragments.

(iv) Evidences of infection at fracture site or pintract infection if any.

(v) Length of tibia.

(3) Radiological Examination:

Initially routine postoperative radiographs of the limbs were taken to check the reduction (Anteriopesterior, lateral and/or oblique views). Oblique view was taken when lateral view was not possible due to overlapping of external fixator. Following points were noted:

(i) Amount of overriding.

(ii) Degree of side to side displacement.

(iii) Degree of angulation.

Second radiograph was taken of every specimen after dissecting the bone out of the soft tissue carefully, without disturbing the position of fragments. Anteriopesterior, lateral and oblique views were taken and again the amount of overriding, displacement and angulation were measured. Presence of radiologically visible callus as well as the visibility of fracture line was noted. Any evidence of infection at fracture site or

the pintract infection was carefully sought for.

Various exposure factors, as well as dark room factors were kept constant throughout the study.

Exposure factors used were:-

Ist X-Ray (check X-Ray)	IInd X-Ray
20 m.a.	10 m.a.
0.5 sec.	0.5 sec.
55 Kv	40 Kv
36 inches Tubes distance	36 inches Tube distance

(4) Mechanical Strength of Callus:

Each experimental tibia was subjected to test the mechanical strength of callus, which was tested under three heads:

(i) Tensile strength.

(ii) Compression strength.

(iii) Angulatory strength.

(i) Tensile Strength:

It was measured by holding the bone in two clamps, each at a distance of 1 cm. from the fracture site. The upper clamp was fixed to a specially designed metallic frame and tension was applied on the fracture site by suspending weights vertically downwards through the lower clamp. The weights were gradually increased till failure occured at the fracture site. The total weight at which the failure occured was noted.

FIG I: DIAGRAMMATIC REPRESENTATION OF THE APPARATUS USED TO TEST THE TENSILE STRENGTH OF THE CALLUS

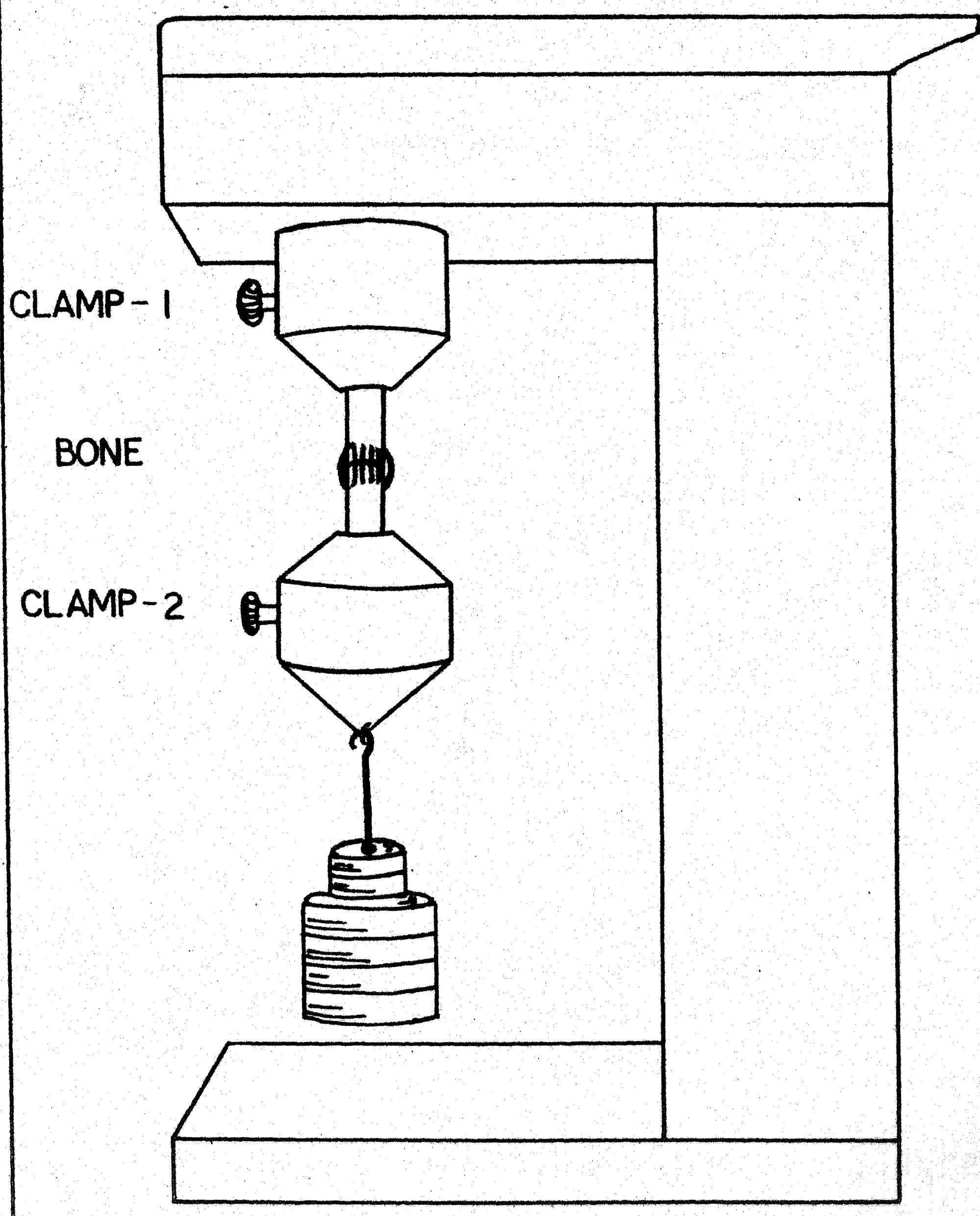


FIG 2: DIAGRAMMATIC REPRESENTATION OF THE APPARATUS USED TO TEST THE COMPRESSION STRENGTH OF CALLUS

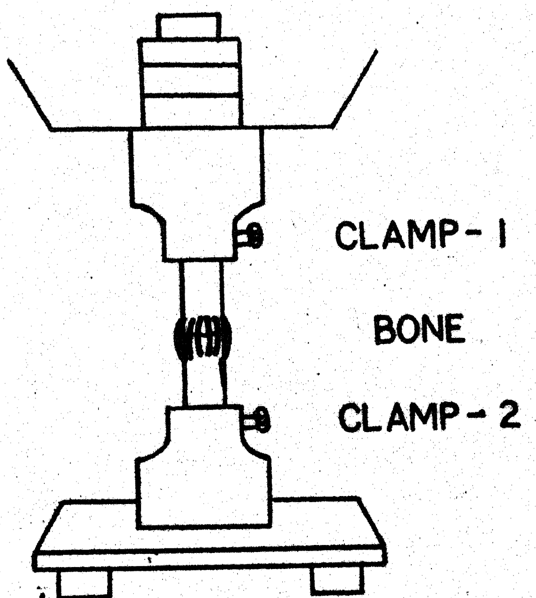
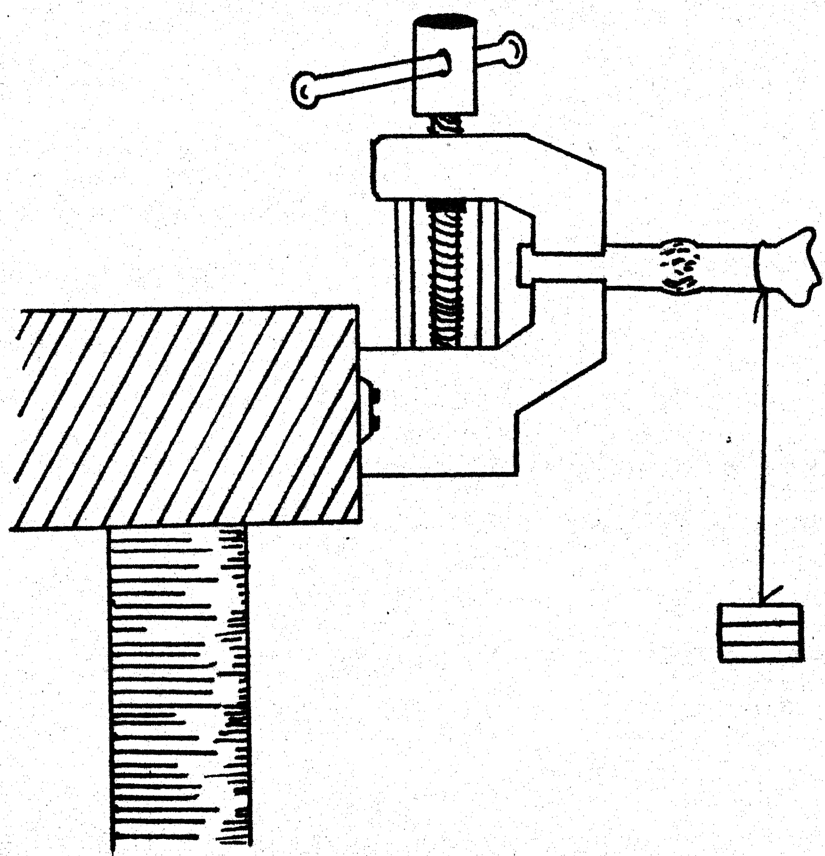


FIG 3: DIAGRAMMATIC REPRESENTATION OF THE APPARATUS USED TO TEST THE ANGULATORY STRENGTH OF THE CALLUS



(ii) Compression Strength:

Amount of compression force to cause failure at fracture site was measured by mounting the bone vertically in two specially designed clamps, each of which was placed. 1 cm. apart from the fracture site. Lower clamp was fixed over a specially designed non compressible metallic base. Vertical compression load was applied by placing weights over a plateform resting on the upper clamp. Load was gradually increased till failure occured at the fracture site. The total weight necessary to cause the failure was noted.

(iii) Angulatory Strength:

To measure the angulatory force necessary to break the callus, the bone was held horizontally in a specially designed clamp. This clamp was applied at a distance of 1 cm. from the fracture site. Angulatory strain at fracture site was produced by suspending weights vertically downwards over the bone at a point 1 cm. away from the fracture site. Weights were gradually increased and the total weight needed to cause failure at fracture site was noted.

All these tests were carried out on a constant height from the ground and were completed within 2 hours of dissecting out the bone, so as to avoid any loss of water content of bone and thus effecting the mechanical strength.

OBSERVATION

O B S E R V A T I O N S

For the present study, the experiments were performed on a total of 98 adult rabbits. Out of these, one animal died during anaesthesia. One animal did not tolerate and nibbled away his plaster, also damaging his foot. In this animal plaster was removed and external fixator was applied. This animal was excluded from study. Other two animals from plaster group died of unknown reasons within a week. One animal from external fixator group developed pintract infection not responding to antibiotics, hence necessiating removal of the pins. Four animals sustained comminuted fracture while producing fracture in the tibia. All these eight animals were excluded from the study, leaving 90 animals on which these observations are based.

These animals were divided in two groups of 45 each according to the method of treatment. Sample size was taken considerably large so as to draw definitive conclusions. Every attempt was made to eleminate any factor which was likely to effect the results and was not common to both the groups.

Animals of both the groups belonged to the same age group, all of them being adult. All the animals were male and belonged to weight group ranging from 1.0 kg to 1.3 kg . Mean weight of animals of group A was 1.21 kg, while the mean weight of animals of group B was 1.19 kg. Similar fractures

were produced in both the groups. Animals who sustained a comminuted or long oblique fractures were rejected. Only the animals with transverse or short oblique fracture and of simple type were accepted for experiments.

CLINICAL OBSERVATION

Postoperatively after recovering from anaesthesia (about an hours time), the animals in group B were seen moving in their cages with a slight limp. After 2nd day onwards they were seen hopping freely in their cages. The external fixation device did not seem to have any inhibitory effect on their activity. All the animals started bearing full weight on the affected limb within one week.

On the other hand, the animals in group A (the plastered group) held the fractured limb close to their body postoperatively and gradually started using the limb after 24 hours, however, none of the animal could have a full weight bearing on the limb.

Four animals in group A developed edema toes on the 2nd day of application of plaster. Edema subsided readily after slitting the plaster cast along it's whole length. No other clinical complication was observed in group A.

In group B, two animals developed clinical signs of mild pintract infection, in the form of slight discharge and induration around the pintract. Both these animals responded

to cleaning and local application of Betadiene solution, supplemented by systemic broad spectrum antibiotic (oxytetracyclin 100mg/kg intramuscular). No other clinical complication was observed.

Animals of group A suffered gross restriction of movement at the knee joint following the immobilisation in plaster cast.

Table No. 1 : Average range of movements at the knee joint of the affected side after different periods of immobilisation

Normal range of movements 0°- 135°

Sl. No.	Period of immobilisation	Group A			Group B		
		No. of animals	Average range	S.D.	No. of animals	Average range	S.D.
1.	2 weeks	9	98.6°	± 3.24	9	full	nil
2.	3 weeks	9	84.2°	± 6.09	9	full	nil
3.	4 weeks	9	50.7°	± 2.80	9	full	nil
4.	5 weeks	9	31.9°	± 3.20	9	full	nil
5.	6 weeks	9	19.7°	± 2.95	9	full	nil
	Total	45			45		

Average range of movements acheived after 2 weeks of plaster immobilisation was 98.60° (normal range 0°- 135°),

which reduced to an average of only 19.7°, after 6 weeks of immobilisation. All the animals (100%) had joint stiffness even after 2 weeks of immobilisation, at the same time no limb on the healthy side had any joint stiffness. On the contrary all the animals of group B enjoyed a full range of movement even after 6 weeks of application of external fixator. No case of any degree of restriction of joint movements was observed (Table -1).

Plaster treated group showed an average shortening of 1.0 cm (average length of normal tibia being 9 cms), while average shortening observed in group B was only 0.1 cm. This difference was statistically highly significant. ($p < 0.001$), (Table - 2).

Table No. 2 : Showing average amount of shortening in both the groups(assessed clinically).

Group A			Group B		
Total No. of animals	Average shortening	S.D.	Total No. of animals	Average shortening	S.D.
45	1.0 cm	± 0.45	45	0.1 cm	± 0.17
		t 13.1,	d.f. 88,	$p < 0.001$	

In plaster treated gour every animal(100%) developed shortening, ranging from a minimum of 0.2 cm to a maximum of 2.0 cm. Maximum animals had a shortening ranging between 0.6 - 0.9 cm (Table - 3).

Table No. - 3 : Showing the amount of shortening of the leg after different weeks of immobilisation.

Sl. No.	Amount of Shortening	Period of immobilisation									
		2 wk.		3 wk.		4 wk.		5 wk.		6 wk.	
		Gr.A	Gr.B	Gr.A	Gr.B	Gr.A	Gr.B	Gr.A	Gr.B	Gr.A	Gr.B
1.	nil	0	4	0	6	0	7	0	8	0	5
2.	< 3 mm	2	3	0	1	0	1	0	1	1	3
3.	3-6 mm	1	2	2	2	0	1	0	0	2	1
4.	6-9 mm	2	0	0	0	4	0	5	0	2	0
5.	9-12 mm	3	0	2	0	2	0	1	0	1	0
6.	12-15 mm	0	0	5	0	2	0	3	0	1	0
7.	> 15 mm	1	0	0	0	1	0	0	0	2	0
Total		9	9	9	9	9	9	9	9	9	9

Out of 45 animals of external fixator group, only 15(33 %) developed shortening. Most of them (9) had a shortening of less than 0.3 cm, other 30(67 %) developed no shortening.

GROSS EXAMINATION

Group A

No fracture could be reduced anatomically. All the specimens showed varying degree of displacement and angulation.

Clinically a soft callus was present around the fracture site at 2 weeks, which in subsequent weeks showed signs of consolidation and was well consolidated in most of the specimen at 4 weeks.

Table No. 4-a : Showing amount of callus after different periods of immobilisation (clinically).

Group A

Period of imm obilis ation.	Amount of Callus										Total
	Abundant		Moderate		Little		V.Little		No Callus		
	No.	%	No.	%	No.	%	No.	%	No.	%	
2 wks.	8	88.9	0	-	0	-	1	11.1	0	-	9
3 wks.	6	66.7	3	33.3	0	-	0	-	0	-	9
4 wks.	2	22.2	5	55.6	1	11.1	1	11.1	0	-	9
5 wks.	2	22.2	4	44.5	3	33.3	0	-	0	-	9
6 wks.	0	-	7	77.8	2	22.2	0	-	0	-	9
Total	18	40.00	19	42.2	6	13.4	2	4.4	0	-	45

Table No. 4-b : Showing amount of callus after different periods of immobilisation (clinically)

Group B (External fixator group)

Period of omm obilis ation.	Amount of callus										Total
	Abundant		Moderate		Little		V.Little		No.Callus		
	No.	%	No.	%	No.	%	No.	%	No.	%	
2 wks.	2	22.2	2	22.2	2	22.2	3	33.4	0	-	9
3 wks.	0	-	4	44.4	1	11.1	4	44.4	0	-	9
4 wks.	0	-	2	22.2	3	33.4	4	44.4	0	-	9
5 wks.	1	11.1	0	-	0	-	8	88.9	0	-	9
6 wks.	0	-	3	33.3	0	-	6	66.7	0	-	9
Total	3	6.6	11	24.4	6	13.3	25	55.7	0	-	45

Table No. - 5 : Showing presence or absence of abnormal movement at fracture site after different periods of immobilisation in both the groups.

Period of immobilisation.	Total No. of animals Gr. A	Total No. of animals Gr. B	Abnormal movements at fracture site: Present: Fully mobile Gr. A	Fully mobile Gr. B	Just mobile Gr. A	Just mobile Gr. B	Absent Gr. A	Absent Gr. B
2 wks	9	9	9(100%)	4(44.4%)	nil	5(55.6%)	nil	nil
3 wks	9	9	7(77.7%)	nil	2(22.2%)	1(11.1%)	nil	8(88.9%)
4 wks	9	9	nil	nil	3(33.3%)	nil	6(66.7%)	9(100%)
5 wks	9	9	1(11.1%)	nil	1(11.1%)	nil	7(77.8%)	9(100%)
6 wks	9	9	nil	nil	nil	nil	9(100%)	9(100%)
Total	45	45	17	4	6	6	22	35

The amount of callus was directly proportional to the displacement of fragments and minimally displaced fractures showed minimal external callus.

Most of the cases (19, 42 %) showed moderate amount of callus, while only 2(4.4%) showed very little callus. 18 animals (40 %) had abundant amount of callus(table No. 4(a).

Table No. 5 shows that abnormal movements at fracture site diminished rapidly from 3rd week onwards. All the specimen exhibited free mobility at fracture site at 2 weeks. At 3 weeks although all the specimens showed abnormal movements, only 7 specimens out of 9 had a free mobility, other 2 were just mobile at fracture site. At 4 weeks callus was consolidated in most of the cases and 6 specimens (66.6 %) had clinical union and showed

no movements at fracture site. At 5th and 6th week, 78 % and 100% specimen respectively acheived clinical union and exhibited no abnormal movements at the fracture site.

Group B

Most of the specimens showed a nearly anatomical restoration of the fragments. Amount of external callus was much less as compared to that in the animals of group A. 25 animals (55.7 %) exhibited only very little callus, though they were clinically firmly united, except the 3 specimen which belonged to 2 weeks group (Table No. 4(b)).

Only 3 cases (6.7 %) showed abundant amount of callus. These cases also had a considerable amount of displacement as well as angulation.

Consistency of callus changed rapidly from 2nd week onwards. Callus started consolidating from 2nd week itself. Only 4 cases were fully mobile at fracture site after 2 weeks, while other 5 cases were just mobile. At 3 weeks 90 % cases (8 animals) had no abnormal movements at fracture site and were firmly united. Only one case was just mobile at fracture site at 3 weeks (Table No. 5)

All the specimens of 4th, 5th and 6th weeks showed a firm union and none of them had any abnormal movement at fracture site (Table No. 5).

RADIOLOGICAL OBSERVATIONS:

In group A, 30 cases (67 %) had a transverse fracture, while 15 (33 %) had a short oblique fracture.

In group B, 28 cases (62 %) had tranverse fracture, while 17 (38 %) had a short oblique fracture.

In group A, no fracture could be anatomically reduced while in group B, 7 cases (16 %) acheived a perfect anatomical reduction. Another 11 fractures (24.4 %) could be reduced to a nearly anatomical configuration, having a displacement of less than 1 mm and an angulation less than 5^{0} in any plane. Thus as a whole, 40 % fractures could be reduced anatomically or near anatomically with the help of external fixator.

In initial check X-Ray in group A, 20 cases (44 %) had no displacement in anteroposterior view. Other 25 (56 %) cases had varying degrees of displacement. Average displacement in group A at the time of plaster was 1.98 mm in Anteroposterior view (Average thickness of the shaft being 5 mm) (Table No. 6-a)

In group B (External fixator group) the displacement at fracture site, as observed in A.P. view were considerably less. 23 cases (51.1 %) had no displacement in A.P. view. Another 9 (20 %) had a displacement of 1 or less than 1 mm. Average displacement after applying the

external fixator was 1.16 mm. in A.P. view(Table No. 6-b)

In both the groups lateral displacement was more common. 17 cases in each group had a lateral displacement, while only 6 and 3 cases in group A and B respectively had medial displacement.

In oblique view (taken because lateral view was not possible due to overlapping of external fixator in group B) the animals of plaster treated group showed much displacement. Only 4 animals (8.9 %) showed no displacement. While 41 animals (91 %) showed some amount of displacement, the average displacement in group A in oblique view was 3.91 mm. (Table No. 7-a). In external fixator treated group 21 animals (46.7 %) showed no displacement in oblique view. The average displacement exhibited was 0.96 mm. which was less than 1/4th of the displacement found in plaster treated group in oblique view (Table No. 7-b).

Change in Displacement during the period of immobilisation

To assess the rigidity of fixation in both the group, any change in displacement during the period of immobilisation was measured by comparing the displacement of initial check X-Ray and the final X-Ray.

Any change in displacement, whether an increase or decrease from the initial position, was noted, as both of them indicate a poor rigidity of fixation at the fracture site.

In the plastered group most of the cases (39 cases, 86.7 %) showed a loss of initial reduction, while in group B (external fixator group) only 3 cases (6.7 %) had a partial loss of initial reduction, rest of 42 cases (93.3 %) had no change in the position of fragments during the period of immobilisation.

Table No. 6-a : Showing change in displacement during period of immobilisation in A.P. view.

Group - A

Sl. No.	Period of immobilisation	Total No. of animals	Initial displacement Average (mm.)	Initial displacement S.D.	Final displacement Average (mm.)	Final displacement S.D.	Change in displacement Average (mm.)	Change in displacement S.D.
1.	2 weeks	9	1.7	±2.2	2.2	±1.7	1.4	±1.6
2.	3 weeks	9	2.2	±2.3	4.0	±1.5	1.7	±1.5
3.	4 weeks	9	2.3	±2.2	3.2	±1.5	2.0	±1.7
4.	5 weeks	9	2.4	±2.2	3.3	±2.1	2.0	±2.0
5.	6 weeks	9	1.2	±1.5	2.2	±1.8	2.1	±1.6
	Total	45	1.98	±2.07	3.0	1.82	1.88	±1.7

Table No. 6-b : Showing change in displacement during period of immobilisation in A.P. view.

Group B

Sl. No.	Period of immobili sation	Total No. of animals	Initial displacement Average (mm.)	S.D.	Final displacement Average (mm.)	S.D.	Change in displacement Average (mm.)	S.D.
1.	2 weeks	9	1.3	±2.2	1.3	±2.2	0	0
2.	3 weeks	9	1.8	±2.1	1.9	±2.2	0.1	±0.3
3.	4 weeks	9	1.2	±1.9	1.2	±1.9	0	0
4.	5 weeks	9	0.6	±0.7	0.6	±0.7	0	0
5.	6 weeks	9	0.8	±0.8	0.8	±0.8	0	0
	Total	45	1.16	±1.65	1.18	±1.65	0.02	±0.15

Table No. 7-a : Showing change in displacement during period of immobilisation in oblique view.

Group A

Sl. No.	Period of immobili sation	Total No. of animals	Initial displacement Average (mm.)	S.D.	Final displacement Average (mm.)	S.D.	Change in displacement Average (mm.)	S.D.
1.	2 weeks	9	3.5	±2.1	4.2	±1.6	0.6	±0.8
2.	3 weeks	9	4.2	±1.3	5.2	±0.8	1.2	±1.2
3.	4 weeks	9	4.3	±2.0	4.4	±1.7	1.2	±1.9
4.	5 weeks	9	4.0	±2.0	4.8	±2.0	1.0	±0.8
5.	6 weeks	9	3.4	±1.9	3.9	±2.4	1.1	±1.0
	Total	45	3.91	±1.89	4.51	±2.0	1.04	±1.19

Table No. 7-b : Showing change in displacement during period of immobilisation in oblique view.

Group B

Sl. No.	Period of immobili sation	Total No. of animals	Initial displacement Average (mm.)	S.D.	Final displacement Average (mm.)	S.D.	Change in displacement Average (mm.)	S.D.
1.	2 weeks	9	1.2	±1.56	1.33	±1.45	0.1	±0.33
2.	3 weeks	9	1.3	±1.4	1.3	±1.4	0	-
3.	4 weeks	9	1.1	±1.27	1.1	±1.27	0	-
4.	5 weeks	9	0.33	±0.5	0.33	±0.5	0	-
5.	6 weeks	9	0.8	±0.97	1.2	±1.4	0.4	±1.33
	Total	45	0.95	±1.66	1.06	±1.8	0.11	±0.75

The average change in displacement in group A was 1.88 mm. (37.6 % of whole thickness of the cortex) while in group B it was negligible as only one case showed a change of 1 mm from the initial position of fragments (Table No. 6-a and 6-b).

In oblique view, the average change in displacement in plastered group (Group A) was 1.04 mm (about 1/4th of the cortex), while in external fixation group only two cases, one from 6 weeks group another from 2 weeks group showed a change in displacement of 4 mm and 1 mm respectively (Table No. 7-a and 7-b)

As is evident from table 6-a and 7-a displacement inside the plaster had an increasing trend up to 4th week after which it has been more or less stationary, probably because of the consolidation of callus around 4 weeks did not allow further displacement.

While the animals in group A had a significant post reduction displacement in both A.P. and Oblique view, the same was insignificant in group B.

The change in displacement during immobilisation when compared in both the groups was significantly much higher in group A. Table 8 and 9 show the statistical analysis of this comparision at every week and corresponding values of p.

Table No. 8 : Statistical analysis of change in displacement in group A and B in A.P. view.

(Refer to table No. 6-a and 6-b)

Serial No.	Period of immobilisation	Degree of freedom (d.f.)	Value of 't'	Value of 'p'
1.	2 weeks	16	2.76	∠ 0.05
2.	3 weeks	16	3.47	∠ 0.01
3.	4 weeks	16	3.6	∠ 0.01
4.	5 weeks	16	3.0	∠ 0.01
5.	6 weeks	16	3.9	∠ 0.01

Table No. 9 : Statistical analysis of change in displacement during period of immobilisation in group A & B in oblique view.

(Refer to table No. 7-a and 7-b)

Serial No.	Period of immobilisation	Degree of freedom (d.f.)	Value of 't'	Value of 'p'
1.	2 weeks	16	2.3	< 0.05
2.	3 weeks	16	3.0	< 0.01
3.	4 weeks	16	1.92	> 0.05
4.	5 weeks	16	3.84	< 0.01
5.	6 weeks	16	3.36	< 0.01

CHANGE IN ANGULATION DURING THE PERIOD OF IMMOBILISATION.

Table 10-a shows the average initial angulation just after the application of plaster and average final angulation at the time of sacrificing the animals at different weeks, as well as the average change in angulation in-side the plaster at different weeks. Corresponding values in group B are shown in table 10-b.

Average initial angulation in group A was 4.8° in A.P. view. Average final angulation was 8.38° and the average change in angulation was 5.1°(as the change in angulation includes both the increase and decrease, it does not necessarily correspond to the difference between initial and final angulation).

Table No. 10-a : Showing change in angulation during period of immobilisation in A.P. view.

Group A

Sl. No.	Period of immobili-sation	Total No. of animals	Initial Angulation Average	Initial Angulation S.D.	Final Angulation Average	Final Angulation S.D.	Change in Angulation Average	Change in Angulation S.D.
1.	2 weeks	9	2.5°	±4.0	4.8°	±5.9	3.5°	±4.2
2.	3 weeks	9	8.3°	±11.6	11.7°	±12.4	5.5°	±5.3
3.	4 weeks	9	2.9°	±3.9	7.1°	±5.1	4.9°	±4.0
4.	5 weeks	9	6.7°	±12.8	11.1°	±13.3	4.4°	±3.5
5.	6 weeks	9	3.6°	±5.1	7.2°	±7.1	7.0°	±5.7
	Total	45	4.8°	±8.3	8.38°	±9.35	6.1°	±4.56

Table No. 10-b : Showing change in angulation during period of immobilisation in A.P. view.

Group B

Sl. No.	Period of immobili-sation	Total No. of animals	Initial Angulation Average	Initial Angulation S.D.	Final Angulation Average	Final Angulation S.D.	Change in Angulation Average	Change in Angulation S.D.
1.	2 weeks	9	7.1°	±9.3	7.7°	±10.8	0.5°	±1.6
2.	3weeks	9	3.4°	±3.3	4.2°	±3.2	0.8°	±2.3
3.	4 weeks	9	5.4°	±6.6	5.4°	±6.6	nil	nil
4.	5 weeks	9	3.8°	±3.8	3.8°	±3.8	nil	nil
5.	6 weeks	9	1.9°	±4.1	1.9°	±4.1	nil	nil
	Total	45	4.33°	±5.35	4.93°	±6.5	0.27°	±1.27

In group B average initial angulation was 4.33°, the final angulation recorded was only slightly higher, being 4.93°. Average change in angulation was 0.27° only. Most of the cases in group B and all the cases belonging to 4th, 5th and 6th week did not have any change in angulation from the initial position (Table No. 10-b). The difference of change in angulation when compared in both the groups was statistically significant at every week. (Table No. 12).

In oblique view also almost similar pattern was observed (Table No. 11-a and 11-b). The mean postreduction angulation in group A was 10.96° as compared to 3.22° acheived in group B thus indicating a poorer reduction in group A.

Table No. 11-a : Showing change in angulation during period of immobilisation in oblique view.

Group A

Sl. No.	Period of immobili sation	Total No. of animals	Initial Angulation Average	Initial Angulation S.D.	Final Angulation Average	Final Angulation S.D.	Change in Angulation Average	Change in Angulation S.D.
1.	2 weeks	9	4.4°	± 7.3	7.2°	±8.8	2.8°	±3.6
2.	3 weeks	9	18.9°	±16.5	22.8°	±16.9	4.3°	±2.9
3.	4 weeks	9	17.4°	±12.2	19.4°	±14.5	5.5°	±3.8
4.	5 weeks	9	8.4°	±12.8	11.9°	±12.4	3.9°	±4.9
5.	6 weeks	9	5.6°	±5.4	5.8°	±6.3	5.8°	±4.1
	Total	45	10.96°	±12.6	13.42°	±13.6	4.47°	±3.92

Table No. 11-b : Showing change in angulation during period of immobilisation in oblique view .

Group B

Sl. No.	Period of immobili-sation.	Total No. of animals	Initial Angulation Average	S.D.	Final Angulation Average	S.D.	Change in Angulation Average	S.D.
1.	2 weeks	9	3.6°	±2.7	3.6°	± 3.6	nil	-
2.	3 weeks	9	2.4°	±3.8	3.0°	± 3.8	0.6°	±1.6
3.	4 weeks	9	3.0°	±5.2	3.0°	±5.2	nil	-
4.	5 weeks	9	4.6°	±6.8	4.6°	± 6.8	nil	-
5.	6 weeks	9	2.4°	±5.0	2.8°	±5.0	0.33°	±1.0
	Total	45	3.22°	±4.8	3.4°	±4.77	0.18°	±1.07

The average final angulation in group A was 13.42°, exhibiting an average change in angulation of 4.47° during the period of immobilisation. On the other hand the animals in group B showed a very neglible deviation from initial angulation and the mean final angulation observed was 3.4° thus exhibiting a very insignificant average change in angulation of less than 1/5th of one degree (0.18°).

The animals in group A and B had an insignificant postreduction angulation in A.P. view. But in oblique view, group A had a significant post reduction angulation while the same was insignificant in group B.

The change in angulation during immobilisation when compared in both the groups was significantly much higher in

group A. Table No. 12 and 13 show the statistical analysis of this comparision and the corresponding values of p.

Table No. 12 : Statistical analysis of change in angulation in group A & B in A.P. view.

(Refer to table No. 10-a and 10-b)

Serial No.	Period of immobilisation	Degree of freedome (d.f.)	Value of 't'	Value of 'p'
1.	2 weeks	16	2.03	$>$ 0.05
2.	3 weeks	16	2.5	$<$ 0.05
3.	4 weeks	16	3.7	$<$ 0.01
4.	5 weeks	16	3.8	$<$ 0.01
5.	6 weeks	16	3.7	$<$ 0.01

Table No. 13 : Statistical analysis of change in angulation in group A & B in oblique view.

(Refer to table No. 11-a and 11-b)

Sl. No.	Period of immobilisation	Degree of freedom (d.f.)	Value of 't'	Value of 'p'
1.	2 weeks	16	2.33	$<$ 0.05
2.	3 weeks	16	3.45	$<$ 0.01
3.	4 weeks	16	4.4	$<$ 0.001
4.	5 weeks	16	2.4	$<$ 0.05
5.	6 weeks	16	3.9	$<$ 0.01

CHANGE IN OVERRIDING DURING PERIOD OF IMMOBILISATION

In group A, 7 cases (15.6 %) could attain normal limb length after reduction. Rest of 38 cases (84.4 %) had a post reduction overriding ranging from 0.1 cm to a maximum of 1.6 cm while in group B 36 cases (80 %) could be reduced to scheive the normal limb length and had no overrding of fragments. Average initial overriding of group A and B being 0.46 cm and 0.05 cm respectively.

In group A, all the cases except two, showed an increase in the overriding during the period of plaster, average increase in overriding being 0.44 cm while in group B, the fracture fragments were firmly fixed and only 2 cases showed an increase in overriding, thus the average being 0.008 cm (Table No. 14).

The amount of postreduction and final overridings observed in group A were statistically significant, while the overriding observed at both the times in group B was insignificant.

The difference of increase in overriding during immobilisation in both groups was statistically highly significant ($p < 0.001$) (Table No. 14).

Table No. 14 : Showing increase in overriding during the period of immobilisation in both the groups (assessed radiologically).

Period of immobilisation	Total No. of animals Gr. A	Total No. of animals Gr. B	Average Overriding initial (cm) Gr. A	Average Overriding initial (cm) Gr. B	Final overriding (cm) Gr. A	Final overriding (cm) Gr. B	Average increase in overriding (cm) Gr. A	Average increase in overriding (cm) Gr. B
2 wks.	9	9	.36±.37	.08±.18	.80±.60	.08±.18	.44±.47	nil
3 wks.	9	9	.30±.28	.12±.16	.80±.50	.14±.18	.50±.40	.02±.06
4 wks.	9	9	.54±.46	.03±.10	.96±.44	.03±.10	.41±.34	nil
5 wks.	9	9	.43±.30	nil	.88±.30	nil	.45±.27	nil
6 wks.	9	9	.56±.52	.03±.07	.94±.50	.06±.13	.38±.33	.02±.06
Total	45	45	.46±.39	.05±.12	.90±.45	.06±.12		

Value of t 8.9

d.f. 88

p < .001

	Gr. A	Gr. B
Average increase in overriding	.44±.32	.008±.04

MECHANICAL STRENGTH OF CALLUS

(1) TENSILE STRENGTH

A marked difference in tensile strength of the callus was observed in both the groups (Table No. 16). Both the groups showed a rapid gain in tensile strength after 4 weeks but the mean tensile strength of callus, as well as, the gain in tensile strength, was much more in group B as compared to group A.

In group A (plastered group) the mean tensile strength at 2 weeks was 7.7 kg which increased to maximum of 14.9 kg at 6 weeks.

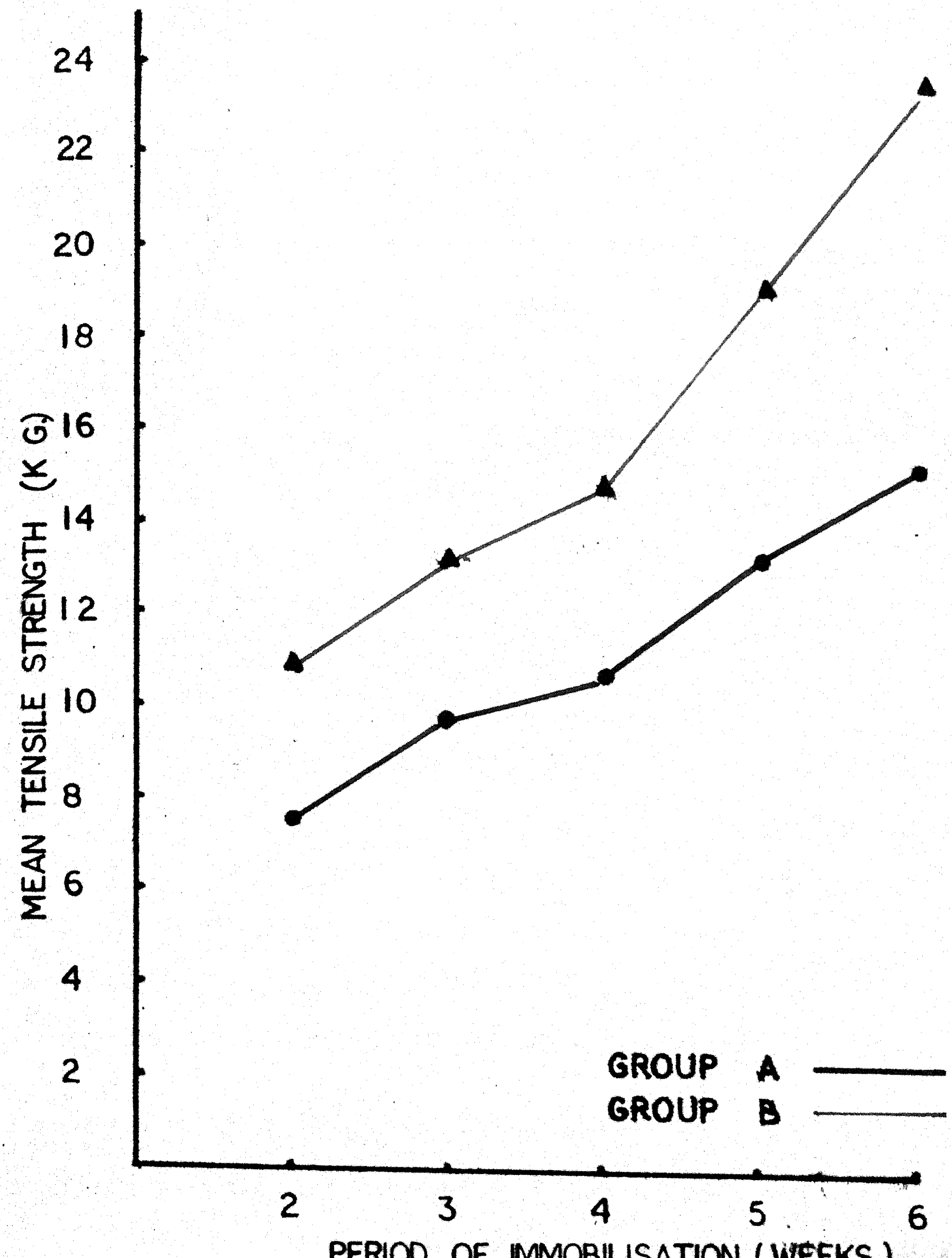


FIG 4: TENSILE STRENGTH CURVES OF CALLUS IN GROUPS A & B.

Table No. 15 : Showing mean tensile strength of callus in group A and B at different weeks.

Period	Group A No.of animals	Group A Mean tensile strength (kg)	Group A (S.D.)	Group B No.of animals	Group B Mean tensile strength (kg)	Group B (S.D.)	't'	d.f.	'p'
2 wks.	3	7.70	± .50	3	10.70	±.95	4.8	4	$\angle$ .01
3 wks.	3	9.76	± .06	3	13.13	±.23	26.3	4	$\angle$ .001
4 wks.	3	10.43	± .21	3	14.60	±.38	17.5	4	$\angle$ .001
5 wks.	3	12.93	± .25	3	18.90	±.36	25.0	4	$\angle$ .001
6 wks.	3	14.90	± .26	3	23.60	±.60	22.5	4	$\angle$ .001
Total	15			15					

In group B (external fixator) group average maximum tensile strength obtained was 23.6 kg while the tensile strength at 2 weeks was 10.7 kg. The 3 week specimen, of group B, acheived a mean tensile strength of 14.6 kg., almost equal to the tensile strength of 6 weeks specimens of group A (mean 14.9 kg.) (Table No. 15). Statistically these differences were highly significant at every week.

COMPRESSION STRENGTH

Values of compression strength of callus were higher than those of tensile strength in both the groups.

In group A the mean compression strength at 2 weeks was 7.83 kg which reached to a maximum of 16.07 kg at 6 weeks.

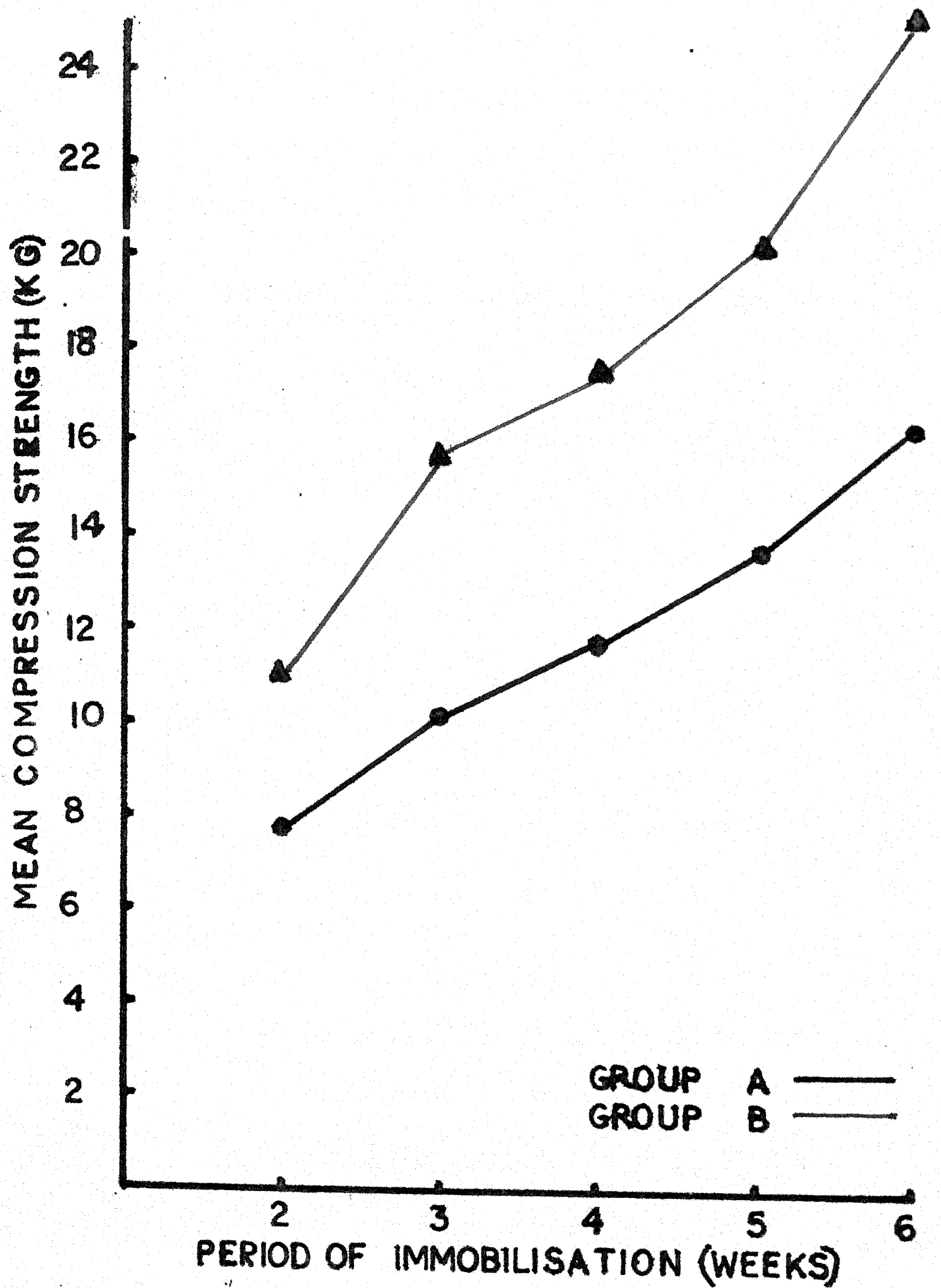


FIG 5: COMPRESSION STRENGTH CURVES OF CALLUS IN GROUPS A&B.

In group B the mean compression strength of callus recorded at 2 weeks was 11.16 (almost equal to the compression strength of 4 weeks specimen of geoup A) (Table No. 16). Maximum compression strength acheived was 25 kg at 6 week.

Table No. 16 : Showing mean compression strength of callus in groups A and B at different weeks.

Period	Group A No. of Animals	Group A Mean Compression Strength (kg)	Group A S.D.	Group B No. of animals	Group B Mean Compression Strength (kg)	Group B S.D.	't'	d.f.	'p'
2 wks.	3	7.83	±.15	3	11.16	±.35	17.0	4	∠ .001
3 wks.	3	10.06	±.35	3	15.76	±.49	16.5	4	∠ .001
4 wks.	3	11.63	±.06	3	17.43	±.59	18.2	4	∠ .001
5 wks.	3	13.60	±.36	3	20.40	±1.06	10.9	4	∠ .001
6 wks.	3	16.07	±.21	3	25.00	±.59	25	4	∠ .001
Total	15			15					

The 4 week specimen, of group B, had a mean compression strength more than that of the 6 weeks specimens of group A. The differences between compression strength in both the groups were highly significent statistically at every week.

ANGULATORY STRENGTH

Angulatory strength of callus was the least of all at any week in both the groups.

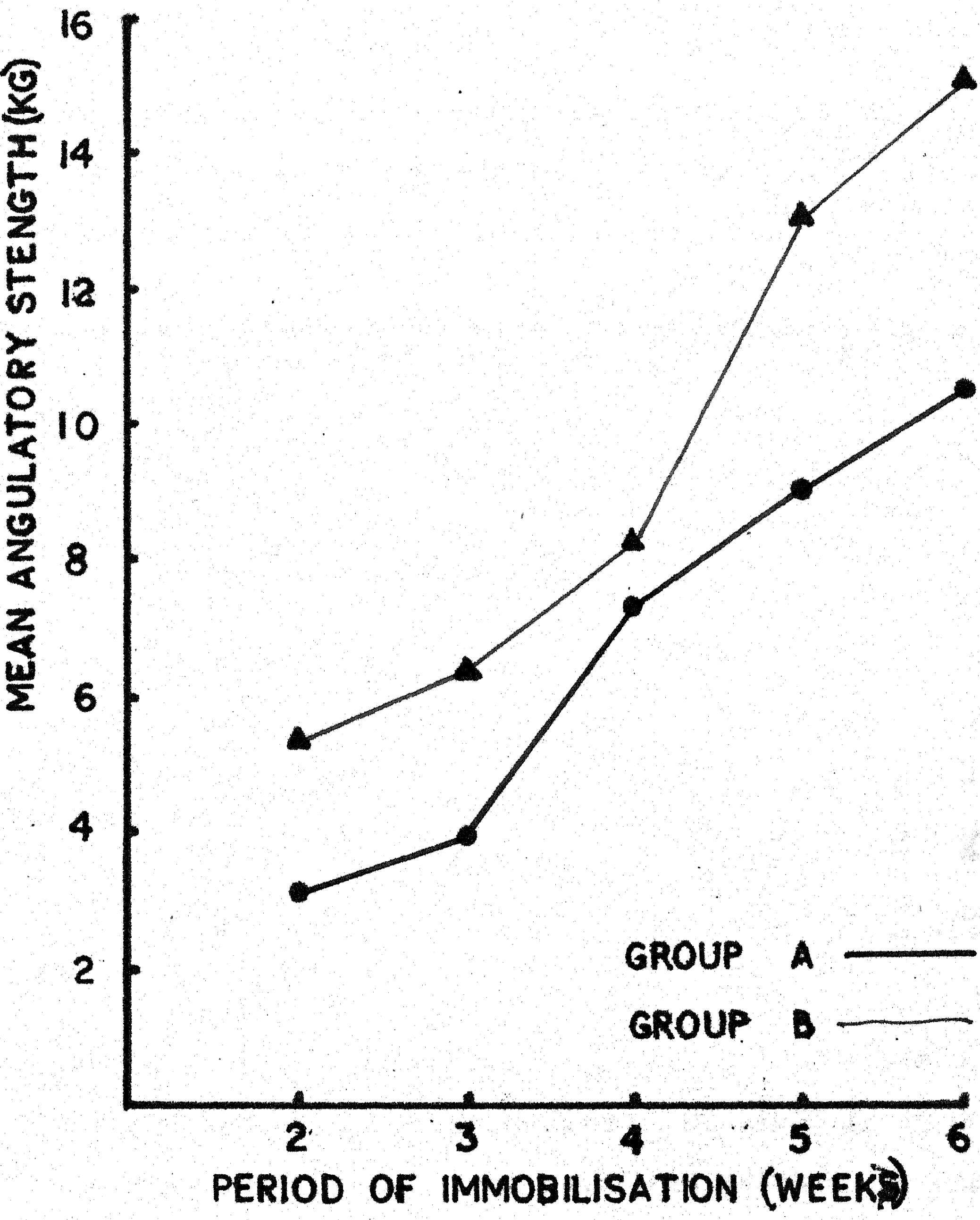


FIG 6: ANGULATORY STRENGTH CURVES OF CALLUS IN GROUP A&B.

In group A the maximum mean angulatory strength obtained was 10.53 kg at 6 weeks. The strength at 2 weeks, was only 3.1 kg. Angulatory strength showed a rapid increase after 3 weeks reaching to it's maximum at 6 weeks.

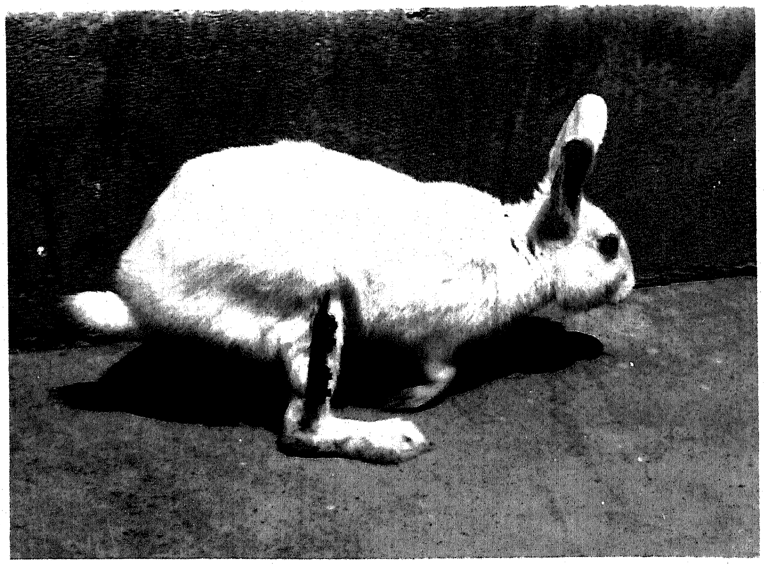
Table No. 17 : Showing mean Angulatory strength of callus in groups A and B at different weeks.

Period	Group A: No. of animals	Group A: Mean Strength (kg)	Group A: S.D.	Group B: No. of animals	Group B: Mean Strength (kg)	Group B: S.D.	't'	d.f.	'p'
2 wks.	3	3.10	±.95	3	5.30	±.46	4.7	4	$<.01$
3 wks.	3	3.93	±.23	3	6.33	±.23	12.9	4	$<.001$
4 wks.	3	7.30	±.70	3	8.20	±.35	1.6	4	$>.05$
5 wks.	3	9.07	±.21	3	13.26	±.31	20	4	$<.001$
6 wks.	3	10.53	±.81	3	16.16	±.45	8.8	4	$<.001$
Total	15			15					

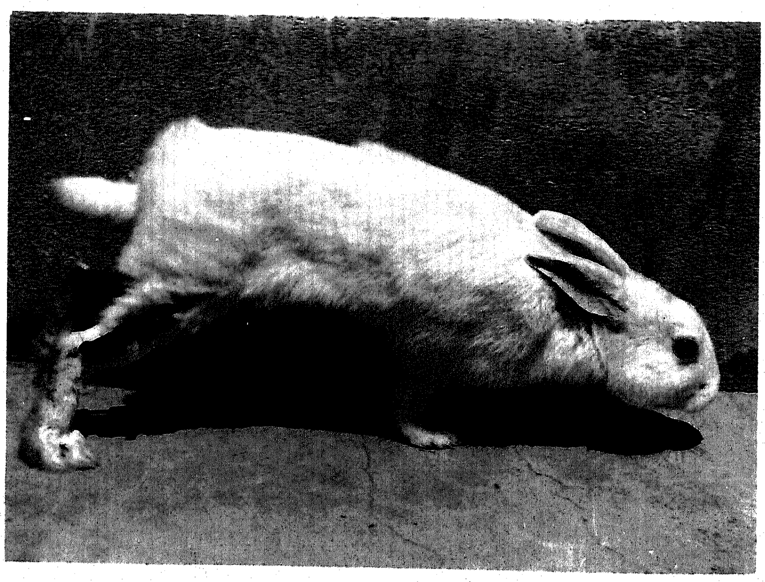
In group B, the mean angulatory strength was 5.3 kg at 2 weeks which increased to a maximum of 16.16 kg at 6 weeks. Although the four week specimen could not acheive the angulatory strength of 6 weeks specimen in group A, the difference between the angulatory strengths in both groups were statistically significant ar every week (Table No. 17).

An experimental animal of group A
with plaster of paris casr.

An experimental animal of group B
with external fixator.

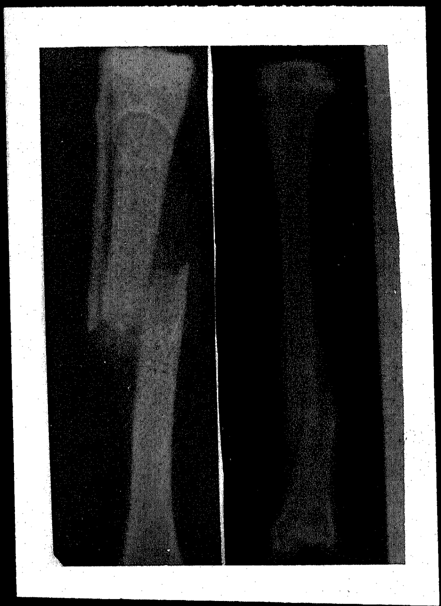


Experimental animal bearing full weight and taking jump two weeks after application of external fixator.

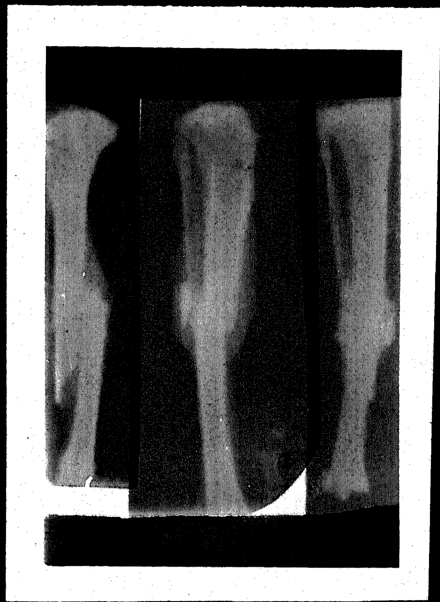


X-Rays of specimens showing amount of callus and state of healing of fracture at diffent weeks.

Group A



2 & 3 weeks



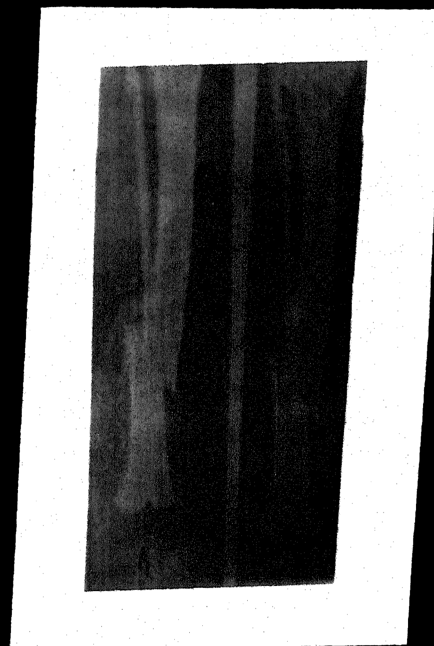
4, 5 and 6 weeks

Group B

Photographs showing quality of reduction acheived in plaster group and change in position of fragments within the plaster.

A. Initial X-Ray

B. Final X-Ray

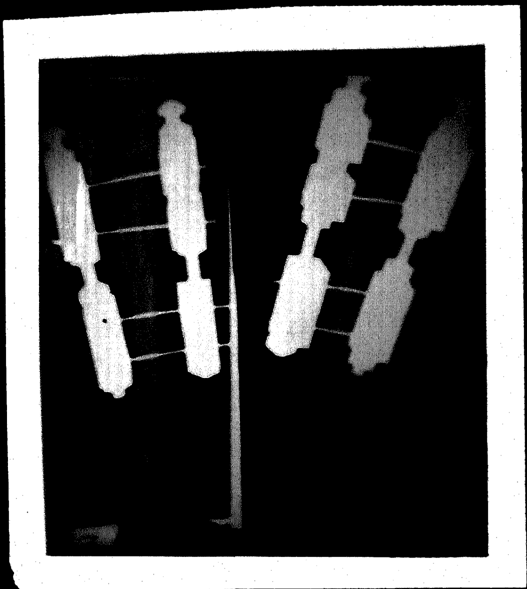


A. Initial X-Ray

B. Final X-Ray

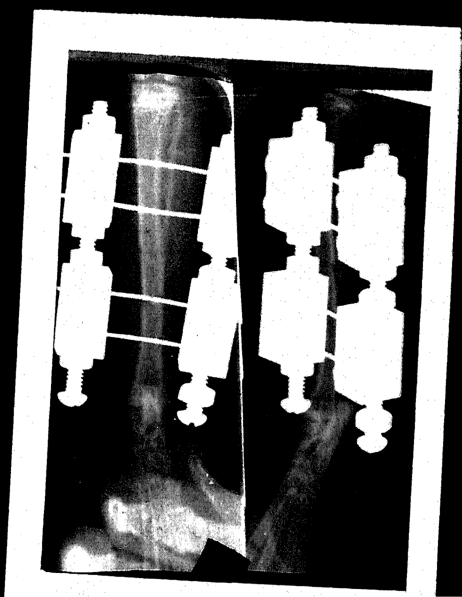
Photographs showing the quality of reduction acheived by external fixator and the firm fixation provided by it.

A. Initial X-Ray



B. Final X-Ray

A. Initial X-Ray



B. Final X-Ray

DISCUSSION

DISCUSSION

Over the last few years, external fixation has come up as a potential method for treating fracture leg, specially that of compound comminuted type. Experimental trials, to evaluate the extent of efficacy of external fixation in the treatment of fracture leg and its effect on the rate and quality of fracture healing, are rather lacking. Hence we have endeavoured to take the present study.

Rabbits were chosen as experimental animal because of their benign nature, easy availability and adequate size to allow application of external fixator.

Every attempts were made to eliminate any factor which was not common to both the groups and could affect either the healing process of fracture or any other observation. Hence all the animals chosen were of same genus, all were male and belonged to a weight group ranging between 1.0 - 1.3 kg . All of them were fed on a standard diet throughout the study.

External fixator used in the study was fabricated by us. While designing the external fixator, the objective was to develop an external fixator which is not only economical to suit Indian conditions, but is also simple, rigid and provides enough adjustability to acheive and maitain maximum

possible reduction alongwith provision to provide compression at fracture site. Most of the external fixator marketed do not meet to all these criterion, are not easily available and are too costly to be afforded by an average Indian patient.

A smaller frame was developed specially, for application in the small experimental animals like rabbits.

Instead of using one side bar we have used 2 side bars, because, by biomechanical studies, the stability of fixation by mounting with one tie bar has been found to be approximately one third of that having mounting with two bars (Aalto, 1980). The biomechanical studies have also revealed the connecting joints between the bars and transfixing pins to be the weakest point of an external fixator (Aalto, 1980), hence these joints have been eleminated from the external fixator used in our study and the transfixing bars have been directly fixed with the help of grub screws on the sleeve of the side bar.

Fracturing the bone manually produced 58 transeverse fractures and 32 short oblique fractures. Very few long oblique or comminuted fractures were produced, which were discarded from the study. Though some workers (Piekarski, 1969, Ellsasser et al., 1975) have preffered to osteotomise the diaphysis to produce a trasverse fracture, we followed the method of Varma & Kumar (1978) to produce a closed fracture

in the shaft of tibia manually and found it completely satisfactory and less traumatising to the soft tissues. It also simulates to the usual mechanism of injury of fracture leg in clinical practice and the transverse and short oblique fractures produced are also of a common type met in clinical practice.

Clinically, the animals not only showed a better tolerance to the external fixator, as compared to the plaster, they started using the fractured limb much earlier than those treated with plaster. 100 % animals of group B, started bearing full weight on the fractured limb within the first week, while none of the animals in group A was able to have a full weight bearing on the injured limb, perhaps because jumping and walking is difficult with the knee and ankle immobilised. In the series of Varma and Kumar, 1973, they also observed the same problem with the experimental animals treated with plaster, while Stader (1942) noted a better tolerance and free movements in experimental animals treated by external fixator.

In clinical studies also, the external fixator is reported to have yielded better results regarding the weight bearing on the injured limb and return to the profession. Mazet (1941) allowed his patients ambulation with the help of crutches

the day after application of external fixator. Most of the workers have observed that partial weight bearing can be started within the first week of application of external fixator(Vinsent et al., 1969),leading to an early return to profession by the patient. On the other hand conservative method of plaster application not only prevents early ambulation, also delays the return to work. Slatis (1967) noted that 90 % of his cases of fracture Leg treated by long leg plaster casts could resume work by 12 months. Michael Alms (1962) found an average period of 22 weeks for absence from the work in patients treated with above knee plaster cast.

Quality of Reduction achieved:

In our study, 18 cases (40 %) could be reduced anatomically or near anatomically with the help of external fixator while none of the cases in the plastered group could be reduced anatomically. A better hold on the fragments as well as the provision for distraction, compression and side to side displacement helped to bring out an accurate reduction in external fixator group.

Varma and Kumar (1973) in their exeprimental study on rabbits, though acheived satisfactory reduction could not acheive anatomical reduction in the plaster treated group. While with the help of external fixator various workers have acheived anatomical reduction in most of the cases both experimentally and clinically (Stader, 1942; Anderson, 1934; Mazet, 1943; Burney, 1970; Edwards, 1972; Lawyer and Lubber, 1980).

In our study, the average displacement remaining after reduction in A.P. view in group A was 1.98 mm (40% of cortex), while in group B it was 1.16 mm (28 % of cortex). In oblique view; the displacements remaining were 3.0 mm and 0.95 mm in groups A and B respectively (Table No. 6 and 7).

Angular deformities remaining in both the groups after reduction were - group A in A.P. view-4.8°, in oblique view - 10.9°. Group B in A.P. view - 4.33° in oblique View 3.2° (Table No. 10 and 11).

Mean overriding observed in group A after reduction was 0.46 cm while in group B it was only 0.05 cm.

Stability of fixation and maintenance of Reduction.

It was generally observed in our study that external fixator provided a very stable fixation of the fracture fragments and the maintenance of reduction throughout the period of immobilisation, was no where comparable to that provided by plaster application.

While in the plastered group all the cases (100 %) showed a loss of reduction or a deviation from the initial position (to assess the rigidity of fixation at fracture site, both the increase and decrease in the initial displacement or angulation were taken to indicate a loose fixation), in group B the fragments were maintained firmly and practically no deviation from the initial position was recorded. Only 5 cases showed a

minimal change in position. This firm fixation of fragments, obtained by applying external fixator, can easily be compared with that obtained after applying internal fixation. Apart from the redisplacement within the plaster, another common problem encountered was the overriding of fragments within the plaster. In our study the animals of plastered group showed an average increase of 0.44 cm (Average length of tibia 9 cm.) in the overriding within the plaster itself. Every animal (100%) showed an increase in overriding of some degree or other. On the contrary, the external fixator did not allow any overriding inspite of a full weight bearing on the limb during the period of immobilisation, except a minimal increase in 2 cases of short oblique type, which might have been produced while tightening the screws during the checkups.

According to Blockey (1956), plaster immobilisation can never give rigid support, no matter, how well plaster is given and also that plaster can never give that degree of fixation which is essential for union is ideal circumstances.

On the other hand, the clinical studies conducted on external fixator have shown the rigidity of fixation, acheived after application of external fixator in accordance of our study (Mazet, 1943; Clansey, 1978; Vidal, 1979; Lawyer, 1980). Biomechanical studies also confirm our observations (Burney, 1979; Chao, 1979; Vidal, 1979).

In the series of Lauger (1980) primary healing occured with external fixator, when the fracture was anatomically reduced and fracture site had minimal movements, as shown by clinical stability, in two to three months, without evidence of visible callus on roentgenogram. Studies have shown that primary bone healing resulted after anatomical reduction and rigid immobilisation which did not permit more than 5-10 micron of motion at fracture site.

TIME OF UNION

Healing of the fractures, treated by plaster immobilisation, occured in 4 weeks time in our study. In most of the cases abnormal movements at fracture site were absent clinically and well consolidated peripheral callus was present radiologically. Varma and Kumar (1973), also observed clinical and radiological union in four weeks in fractured legs of rabbit, treated by plaster immobilisation.

In group B, most of the cases lost the mobility at the fracture site at the end of two weeks, however radiological union was present at three weeks in majority of cases.

Varma and Kumar (1973), though, did not have a group of animals treated by external fixator, they studied the fracture healing in rabbit tibia after stable internal fixation and found the time of clinical and radiological union to be the

same as that of the plastered group.

Comparing our results with those of Verma & Kumar (1973) it can be concluded that with application of external fixator, union can be acheived much earlier as compared to those cases, where either plaster cast or internal fixation has been used as a method of treatment. The reasons can be many. As outlined by Mazet in 1943, the following advantages of external fixation are also reported to have a favourable effect on fracture healing, leading to an earlier and stronger union.

1. Perfect and accurate reduction.
2. Firm fixation and maintenance of reduction.
3. Provision for compression.
4. Avoidence of distraction.
5. Early mobilisation and weight bearing.

Rhinelander in 1968, while studying the healing by microangiography in dogs, observed that in cases of stable reduction of fragments, the medullary circulation crossed the fracture gap within at least three weeks but when the reduction was unstable, the cheif medullary arteries remained blocked at the fracture fibrocartilage for a longer period. He also reported that when the fracture fragments were stable osseous callus at 3 weeks had united the portion of living

cortex across the fracture line.

According to Varma & Mehta (1967), perhaps continued mobility, following loose fixation, is responsible for prolonged relative or complete avascularity at the fracture site, by hampering with the ingrowth of the capillaries, which does not take place till the mobility is reduced by formation of primary fibrocartilagenous callus, favoured due to low oxygen tension caused by relative ischaemia. When the fracture is rigidly immobilised, the ingrowth of capillaries can take place more rapidly and hence there is direct bone formation.

Compression over the fracture site also helps in promoting bone union (Basset, 1962; Anderson, 1965; Simmons, 1980), which can be very effectively provided by the external fixator.

Basset's (1962) work, on tissue culture has shown that premitive mesenchymal cells, exposed to high oxygen concentration and tension, developed into osteoblasts. Low oxygen tension or distraction produced fibroblasts.

Anderson (1965), holds that compression appears to be beneficial in cortical bone healing because it increases the rigidity of fixation by impacting the bone ends and the space between the bone ends, which must be bridged by new bone, is narrowed. He achived 100 % union of osteotomies in

experimental animals, sacrifised 6 weeks after the operation, with direct cortical healing of osteotomies by treating with rigid fixation by compression plating.

External fixator also seems to accelerate the bone healing by not draining the fracture haematoma and not distu rbing the formation of either the endosteal or peripheral callus. While the contrary is true for internal fixation which not only drains the fracture haematoma also hampers with the formation of either endosteal or periosteal callus.

QUANTITY OF CALLUS

In our study healing occured mainly by peripheral callus in group A. In most of the cases either an abundant callus(18 cases, 40 %) or moderate amount of callus (19 cases 42 %) was found. On the other hand in group B, most of the animals (25, 55.7 %) had a healing with a very little amount of callus, though clinically having a sound union. Similar observations were made by Varma and Mehta (1967), Schenk and Willengger (1964), Anderson(1965), Lettin (1968), Varma & Kumar (1973), Lane(1979), Li (1979), while studying fracture healing in experimental animals under different types of fixations.

According to Anderson (1966), there are three areas of osteogenic potential in healing of any diaphyseal fracture.

1- Periosteal reaction.

2- Endosteal or medullary callus.

3- Fracture haematoma.

The cortical fracture ends are a fourth possible area of osteogenic potential.

In the fractures, treated with inadequate fixation or those with marked overriding of fragments, union is almost entirely by massive formation of cartilage within organising fracture haematoma and gradual conversion of this cartilage to bone by enchondral ossification. This was the case with the animals in group A treated by plaster cast. Varma & Kumar (1973) also found an abudant peripheral callus, in the healing fractured tibiae, of rabbits treated by plaster cast.

Fractures treated by medullary nails, must unite by peripheral callus because, nail blocks endosteal callus and on the other hand, the plate and screw fixation also produce some damage to the medullary and cortical blood supply, by periosteal stripping. The peripheral bone formation from periosteum and bone formation in fracture haematoma, most of which is drained out are not prominent. External fixator, on the contrary, does not hamper with either medullary vascular system or the normal effective blood flow of the cortex and thus allows the most desirable normal physiological bone healing to take place. Still in our study very little callus was demonstrable in most of the cases treated by external fixator while a sound union had been acheived. This can be explained

by the accurate reduction achieved and rigid fixation permitting no movements at fracture site (Hicks, 1969; Hutzschenreuter, 1969).

Our observations are in confirmity with those of Lawyer & Lubber (1980), who clinically acheived a primary bone healing in fractured tibiae, treated by external fixator, in most of the cases. Clinical stability was acheived, without evidences of visible callus on roentgenogram.

Hicks (1960) pointed out that, the amount of callus varies with the degree of rigidity involved. Similar were the observations of Hutzschenreuter (1969).

Lane (1979), and Li (1979), studying the effect of immobilisation on the healing fractured tibiae of rats, observed maximum callus size in mobilised tibiae at 4th week. In their model the firmly fixed and immobilised limbs developed a very sparse external callus, with neglible amount of cartilage demonstrable histologically. Moreover, the bone healed by direct membranous bone formation.

MECHANICAL STRENGTH OF CALLUS

Whatever may be the mode of treatment of fractures, the ultimate aim is to acheive a sound union. Thus the mechanical strength of the callus obtained with a particular method is of paramount importance to establish it's supremacy over the other existing methods of treatment.

Since the variety of possible mechanical tests to which a healing bone can be subjected is virtually infinite, it has been difficult, if not impossible to compare data on the strength of callus obtained by many of the previously used techniques.

In addition to variations in test configurations, variations of test duration lead to a significant changes in observed results (Burstein, 1971). For example, human tibia can absorb 46 percent more energy when broken at strain rates equivalent to trauma than when the bones were broken over a period of several minutes(Frankel and Burstein, 1965).

However, using a standard mechanical test with identical methodology results can be compared between different groups in a single study.

In our study mechanical strength of callus was noted in both the groups using same methodology. As it was not possible to carry out the tests at a particular point of time, all the tests were perfomed within 2 hours of dissecting out the bones thus affecting the results. Three types of loading configurations were used.

1. Axial compression.
2. Axial tension.
3. Bending loading configuration - using one support and a single loading point.

1. TENSILE STRENGTH:

In group A the tensile strength recorded was at its maximum (14.9 kg) at 6 weeks. While the same in group B was 23.6 kg. The difference being statistically highly significant ($p \angle 0.001$). In both the group, tensile strength showed a rapid increase after 4th week. The tensile strength of callus in group B at 3 weeks was almost equal to that in group A at 6 weeks.

By applying axial tensile stress the strength was clearly much more in the bones treated by external fixator in all the specimens.

These observation in group A are similar to those made by Varma & Kumar (1973) on the fractured tabbit tibiae treated by plaster.

Peikarski et al. (1969), also observed that tensile strength acheived in fractures of rabbit's radii, treated without any internal fixation, showed a rising trend up to the end of study i.e. 6th week.

2. COMPRESSION STRENGTH

Compression strength showed a similar trend as that of the tensile strength in both the groups. However the values of compression strength were a little higher than those of tensile strength at corresponding weeks in both the groups. Mean compression strength at 4 weeks in group B (17.4 kg) was more than that in group A at 6 weeks (16.07 kg). The difference in compression strength in both the groups were statistically

highly significant at every week ($p < .001$)

3. ANGULATORY STRENGTH

Though angulatory strength also maintained more or less the same pattern, the values were much lower in both the groups, because, the leverage acting over the fracture site increases the resultant stress by many folds. Angulatory strength in group A was 3.1 kg at 2 weeks and reached to a maximum of 10.63 kg at 6 weeks. Corresponding values in group B were 5.3 kg and 15.16 kg respectively. The difference in angulatory strength in both the groups at different weeks were statistically significant.

Our results of mechanical strength of callus are also in confimity with those of Pickarski (1969), who explained the low strength of callus, having a large cross section, by the greater porosity of such a callus.

These mechanical tests clearly indicate that mechanically the callus obtained in group B, was much stronger in every parameter (compression, tension andangulation) at any period of healing,as compared to that in group A. It is also obvious that the callus observed in group B though much less in volume was well consolidated and much stronger than the voluminous but poorly consolidated callus observed in group A.

COMPLICATIONS

In our study, main complications encountered in group

A, were joint stiffness, shortening and malunion. While in group B complications observed were minimal like a few cases of pintract infection.

Incidence of joint stiffness was 100% in plaster treated group, while it was zero in group B. Average range of movements obtained at knee joint after 6 weeks of plaster immobilisation was 19.7°. The animals in group B enjoyed a full range of movements (0°- 135°) even after 6 weeks of application of external fixator.

Joint stiffness has been a common problem with conventional plaster treatment. Almost every worker has reported the similar results after plaster immobilisation. (Solheim, 1960; Nicoll, 1964), While, after application of external fixator, the incidence of joint stiffness is almost nil as the patient can move his joints through their full range and physiotherapy to preserve the muscle power and avoid the wasting can be initiated from the very beginning. In clinical studies also, the observation of other workers are consistent to our findings (Shear and Kraus, 1944,; Solheim, 1960; Kenwright, 1980; Lawyer and Lubber, 1980;; Aho et al. 1980; Edge & Denham, 1981).

Shortening observed in our study was significantly much in group A animals, the average being 1.0 cm (average

length of normal leg of rabbit 9 cm). Average shortening exhibited by group B animals was 0.1 cm only. This difference was statistically highly significant ($p < .001$).

This insignificant amount of shortening in group B, can be explained by a better reduction acheived and the maintenance of limb length by the external fixator, while, plaster immobilisation allows some amount of overriding, specially in cases of oblique fractures and where an overriding existed at the time of application of plaster.

Significant shortening of leg, after treatment with plaster cast has been a major and consistent problem, as observed by various workers clinically (Oskar Lindon, 1938; Lottes, 1952).

With the use of external fixator, shortening has not been reported to be a significant problem, except in cases having bone loss (Naden, 1949).

After application of plaster edema was observed in 4 animals which readily subsided after slitting the plaster through its whole length.

Some of the complications reported to occur rarely with the use of external fixator, like loosening of pins, bending of pins (Edge & Denham, 1981) and breaking of pins (Naden, 1949; Burney, 1979) did not occur in our study. Bending or breaking of transfixing K wires did not occur probably because of them being strong enough for rabbit tibia.

However pintract infection did occur in 3 cases (6.6 %). All of them reponded to antibiotics, except one necessiating removal of external fixator and and exclusion from study. Incidence of pintract infection has been encountered variably by different workers. While, some have observed this complications to occur in their series, incidence ranging from 2 % to 40 % with different workers (Naden, 1949, Burke, 1977; Aho, 1980; Lawyer and Lubber, 1980; Edge & Denham, 1981). Others have found no incidence of pintract infection (Shaar & Kreuz, 1944; Cotton, 1979). This incidence of pintract infection in our study could be because, we did not use any antibiotics pre or post operatively. However, pintract infection was not much of problem in our series, as most of the infections subsided after antibiotic administration.

Infection occuring after internal fixation not only involves the fracture site only, but may spread to the whole diaphysis and to eradicate it, may be too tedious a task, while, with external fixator the pintract infection is usually localised and at a distance from fracture site.

No infection was reported in plastered group.

Based on these experimental observations in cases of fracture leg the external fixator seems to offer a method of treatment, which is simple, safe, provides better reduction

rigid fixation, better and early fracture healing, permits early ambulation and is relatively free of complications as compared to the conventional method of plaster immobilisation.

CONCLUSION

C O N C L U S I O N

Following conclusions were drawn, based on the present study, conducted at the experimental research laboratory of M.L.B. Medical College, Jhansi.

1- Application of angulatory force manually, is a satisfactory and simple method to produce a closed fracture in the mid shaft of long bone, in an experimental animal, for the purpose of similar types of studies.

2- External fixator, helps to bring about an accurate and in most cases an anatomical reduction in cases of fracture both bone leg. While manually, an anatomical reduction can usually not be acheived.

3- A very rigid fixation of fracture fragments can be acheived by applying an external fixator, while a plaster cast fails to do so and allows some movements at fracture site, no matter how well it is applied.

4- With a rigid external fixation device, almost immediate weight bearing can safely be initiated, with a full weight bearing within a week.

5- Time taken for fracture union is considerably less with application of external fixator, while fracture treated by plaster take a much longer time to unite.

6- Primary union of fracture can usually be acheived with application of external fixator, while this is an exception with plaster treatment.

7- Amount of callus is directly proportional to the movements occuring at the fracture site, as well as the displacement of fracture fragments. Fractures treated by plaster, usually unite by a large callus, while those treated by external fixator usually develops very little callus.

8- Compression at fracture site not only increases the rigidity of fixation, also accelarates the process of fracture healing. Compression at fracture site can be very effectively provided by an external fixator device.

9- Compression strength of a healing fracture is more than it's tensile strength which in turn is more than it's angulatory strength.

10- The callus obtained by applying an external fixator, though much smaller in volume is mechanically much stronger than the callus of same age after plaster treatment. Union acheived by an external fixator is also much stronger than that acheived by plaster application.

11- Joint stiffness is an inevitable complication of a long leg plaster cast, while application of external fixator almost eleminates this complication.

12- Incidence and amount of shortening of leg after plaster treatment is much more as compared to that after treatment by external fixator.

13- Pintract infection, is not much of a prblem with an external fixator and can easily be avoided by routine antibiotic adminstration.

On the whole on the basis of this study, it can be validly concluded that as compared to conventional plaster treatment for fracture both bones leg, external fixator not only helps to acheive an accurate reduction, also maintains a rigid fixation of fracture fragments leading to an early and better quality of union, which is much stronger mechanically. It is accompnied by a minimum of complications and simultaneously eleminates most of the complications of plaster treatment. Hence its use in clinical practice for complicated and uncomplicated fracture both bones leg is strongly recommended.

BIBLIOGRAPHY

B I B L I O G R A P H Y

1. Aalto, K. and Karaharju, E. : The stability of external fixation device, Acta orthop. Scand. 52 : 591, 1981.
2. Aho, A.J.; Nylamo, E. and Hiesinens : External fixation of tibial fractures with the Hoffmann-Vidal Adrey Osteotaxis, Acta Orthop. Scand. 52 : 445, 1981.
3. Amesbury, J. (1827) : A syllabus of surgical lectures on the nature and treatment of fractures, diseases of joints and deformities of limbs and spine. T. and G. Underwood, London.
4. Anderson, L.D. (1965) - Compression plate fixation and the effect of different types of internal fixation and fracture healing. Journal of Bone and joint surgery 47-A, 191.
5. Anderson Roger : An automatic method of treatment for fracture tibia and fibula, Surg. Gynaec. and Obst. 58 : 639-646, 1934.
6. Anderson Roger and Finlayson, B.L. : Sequelae of transfixation of bone, Surgery 13 : 46 - 54, 1943.
7. Basset, C.A.L. (1962): Current concepts of bone formation, J.Bone joint Surg. 44A 1217.
8. Blocky, N.J. : The value of rigid fixation in the treatment of adult tibial shaft. J.Bone Joint Surg. 38-B, 518, 1956.
9. Burke, D.L. : Oliver, J.H. and Purcell, G. : Experience with the use of the Hoffmann External Fixation apparatus,J.Bone joint Surg. 59-B, 510, 1977.

10- Burny Frans, L. : Elastic external fixation of tibial fractures, study of 1421 cases, In Brooker A.F. and Edwards C.C., art, Baltimore, 1979, the Williams & Wilkins Co.

11. Burney F. et al. : External fixation treatment of fractures of the humerus. Acta Orthop. Belg. 1979, 45/1 (47-56).

12. Burstein,A.H. , Frankel, V.H. : A standard test for laboratory animal bone. J. Biomechanics Vol. 4, p 155-158. 1971.

13. Burwell, H.N. : Plate fixation of tibial shaft fractures, J. Bone Joint Surg. 53-B, 258-271, 1971.

14- Chao Edmond, Y.S. ; Briggs, B.T. and McCoy, M.T. ; Theoretical and experimental analysis of Hoffmann-Vidal External fixation system. In Brooker, A.F. and Edwards, C.C. Editors, External fixation, the current state of the art, Baltimore, 1979, The Williams & Wilkins Co.

15. Charak Samhita (1949): Edited and published by shree gulabjunverba Ayurvedic Society, 6, Vols, Jam Nagar.

16. Charnley, J. (1944) : Compression Arthrodesis, Edinburgh Livingston.

17. Clancey, J.; Garay and Hansen Sigvard, T. : Open fracture of tibia, A review of 102 cases, J.Bone Joint Surg. 60-A, 118, 1978

18. Clayton Parkhill : Report of fracture committed, Brit.Med. Jr. 1503-1523, 1912.

19. Sodiville : Report of fracture committed, Brit.Med. Jr., 1503-1523, 1912.

20. Cotton Ralph, L. : A clinical study of tibial fractures using Hoffmann external fixation, In Brocker. A.F. and Edwards, C.C., Editors; External fixation, the current state of the art, Baltimore, 1979, the Williams & Wilkins CO.

21. Davis, A.G. : Pin distraction as the cause of non union, J.Bone joint Surg. 26, 631-643.

22. Edge, A.J. & Denham R.A. : External fixation for complicated tibial fractures, Jr. Bone Joint. Surg. 63-B, 92, 1981.

23. Edwards Charles, C. : Management of the Polytrauma patient in a major U.S. Center. In Brocker, A.F. and Edwards, C.C. Editors, External fixation, the current state of the art, Baltimore, 1979, the Williams & Wilkins Co,

24. Edwards P. : Fracture of the shaft of tibia, 497, Consecutive cases in adult. Acta. Orth.Scand.Suppl. 76, 1965.

25. Elisasser, C. James; Moyer, F. Carl (1975): Improved healing of experimental long bone fractures in rabbits by delayed internal fixation. Jr. of Trauma, Vol. 15, No. 10, 869-875.

26. Enneking, W.F. (1948) : The repair of complete fracture of rat tibias; Anatomical records, 101, 515.

27. Frankel, V.H. and Burstein, A.H. (1966) : Local capacity of tubular bone. Biomechanics and related bioengineering topics(edited by R.M. Kennedi) Chap.32, 381-396, Pergamon Oxford.

28. Freeman, L. : Ann Surg. 70 : 221, 1919.

29. Gallie, W.E. and Robertson D.E. : Repair of bone. Brit.J. Surg. 7, 211-261, 1919.

30. Gibson Tom and Wilson Elizabeth : The History of Orthotics. In the advances in orthotics ed. by George Murdoch, 1976. Pub. by Edward Arnold London.

31. Griswold, R. Arnold and Holmes George, W. : Double pin skeletal fixation in fractures of leg, Surg., Gynaec. and Obst. 68 : 573 - 576, 1939.

32. Ham, A.W. and Harris, W.R. (1956) : Repair and transplantation of bone. In Biochemistry and Physiology of bone. Ed. by Bourne, New York Academy Press.

33. Hicks. J.H. : Internal fixation of fractures. In Modern trends in accident surgery and medicine. Ed. by R. Clarke F.G. Badger and S. Sevitt. London. Butterworths, 196, 1959.

34. Hoffmann, R. : Acta Chir. Scan. 107, 72, 1954.

35. Kamhin M. et al. (1978) : The use of external skeletal fixation in the treatment of fracture of humeral shaft. Inj. 9, 245.

36. Karlstrom, et al. : The management of tibial fracture in alcoholics & mentally disturbed patients. J. Bone joint Surg., 56-B, 730-734, 1974.

37. Keswani, N.H. : Ancient Hindu orthopaedic surgery. Ind. J. Ortho. Vol. 1 : No. 1, June, 1967, p 76-94.

38. KÜdarna, H. : Treatment of compound comminuted and multi-fragment fractures with special consideration of Hoffmann osteotaxis. Unfallheilkunde 1977, 80/12 (523-535).

39. Lambotte, A. : Operative treatment of fractures, Brit. Med. Jr., 1912, 1530-1532.

40. Lane, J.M. ; Li, W.K.; Eaton, B., Dick, B.L. and Elaine G : Effect of immobilization on fracture callus matrix, collagen, Proteoglycan and mineral metabolism. Trans. Orthop. Res. Soc. 4.4, 1979.

41. Lawyer Ruskin B. and Lubber Lawrence, M. : Use of the Hoffmann apparatus in the treatment of unstable tibial fractures, J. Bone Joint Surg. 62-A : 1264, 1980.

42. Lettin AWF (1968) : The bioligical effect of rigid internal fixation on the healing of cortical bone. Journal of bone and joint Surg. 50-B, 227.

43. Lewis, K.M., Breidenbach, L. and Stader, O. : The Stader reduction splint for treating fractures of the shafts of the long bones. Ann. Surg. 116 : 623-639, 1942.

44. Li, W.K.; Lane, J.M.; Seighal, T. ; Horowitz, D.; Eaton, B., and Dick, B.L.: Matrix Constituent alterations in fracture non unions. Trans. Orthop.Res.Soc. 4, 7, 1979.

45. Lottes, J.O., Hill, L.J. and Key, J.A. : Closed reduction Plate fixation and medullary nailing in fracture both bone leg. J. Bone Joint Surg. 34-A, 861, 1952.

46. Malgaigne and Levi : In Brooker, A.F. and Edwards, C.C. Editors: External fixation, the current state of the art, Baltimore, 1979, the Williams & Wilkins Co.

47. Mazet Robert : The use and abuse of the anatomic splint in the treatment of fractures of the lower extremity, J. Bone Joint Surg. 25-A : 839, 1943.

48. McLaughlin. Harrison L. : Open reduction internal fixation of fracture of long bones. J. Bone Joint Surg., 31-A, 1949.

49. McLean F.C. and Urist M.R. (1961) : Bone - An introduction to physiology of skeletal tissue, 2nd Ed. University of Chicago Press p. 200.

50. Michael Alms : Medullary nailing for fractures shaft of tibia. J. Bone Joint Surg. 44-B, No. 2, May 1962.

51. Naden John, R. : External fixation in the treatment of fractures of the tibia. J. Bone Joint Surg. 31-A: 586 - 598, 1949.

52. Nicoll, E.A. : Fracture of Tibial shaft - A Survey of 705 cases. J. Bone Joint Surg. 46-B, 373, Aug, 1964.

53. Nilsonne, Ulf (1961) : Biophysical investigations of mineral phase in healing fractures. Acta. Orthop. Scand. Suppl. 37.

54. Oscar Lindon : Results of treatment by reduction and plaster. Acta. Chir. Scand. 83, 365, 1938.

55. Phemister, D.B. : Bone growth and repair, Ann. Surg., 102, 261-285, 1935.

56. Pickarski, K., Wiley, A.M. and Barttels J.E. (1969). The effect of delayed internal fixation on fracture healing. Acta orthop. Scand. 40, 543-551.

57. Rasmian, S.M. (1971) : The effect of new external fixation in treatment of fractures of long bones. Ann. R.Coll. Surg. Engl. 48, 336.

58. Rhinlander, F.W. : Tibial blood supply in relation to fracture healing. Clin. Ortho, 105, 34-81, 1974.

59. Seligson, D. & Kristiensen,T.K. : Use of wagner apparatus in complicated fractures of distal femur. J. Trauma 18/12, 795-799, 1978.

60. Savigny J.H.(1798) : A collection of engravings, representing the most modern and approved instruments used in practise of surgery. London.

61. Schenk, Rand Willenger, H. : Zur histologie der primaren knochenheilung Langenbecks Arch Chir 1964, 308,440-52.

62. Shaar, C.M. and Kreuz, F.P. : Treatment of fractures and bone and joint surgery with the Stader reduction and fixation splint, surg. Clin. North, America 22: 1537-1583, 1942.

63. Shaar, C.M.; Kreuz, F.P. and Jones, D.T. : End results of treatment of fresh fractures by the use of Stader

apparatus. J.Bone joint Surg. 26: 471-474, 1944.

64. Simmons,David,J. : Fracture healing. In fundamental and clinical bone physiology. Ed. by Marshall, R. Urist. J.B. Lippincott Company. Philadelphia, 1980, p 293 - 296.

65. Singhal, G.D. (1977) : Diagnosis of fractures and dislocations in Ancient Indian Surgery. Ind. J. Orthop. Vol. II, No. 2, Dec. 1977, p 156 - 158.

66. Slatis P. and Robbenen, P. : Conservative treatment of tibial shaft fracture. Acta. Chir. Scand., 134, 41-47, 1967.

67. Solheim, K. : Fracture of lower leg. Acta. Chir Scand., 119, 268 - 279, 1960.

68. Solheim, K. : Disabilities after shaft fracture of bones of leg. Acta.Chir.Scand., 119, 280-287, 1960.

69. Stader, Otto: The Stader reduction splint for treating fractures of the shafts of the long bones. Ann.Surg. 116 : 623 - 639, 1942.

70. Steinmann, F. : Report of fracture committed. British Med. J. 1912, 1603, 1623.

71. Varma, B.P. and Kumar V. (1973) : The effect of varying degree of fixation on the healing of closed diaphyseal fractures - An experimental study. Indian Journal of Orthopaedics. Vol 6-7, 1973, p 97 - 106.

72. Varma, B.P. and Mehta, S.H. (1967): Fracture healing with intramedullary nail fixation of the long bones. Acta Orthopaedica Scandanvica, 38, 419.

73. Vidal, J. : Adrey, J. : Connes Henry and Buscayret, C.: A biomechanical study and clinical application of the use of Hoffmann external fixator. In Brocker, A.F. and Edwards, C.C. Editors; External fixation, the current state of the art, Baltimore, 1979, the Williams & Wilkins Co.

74. Vidal, J. : Buscayret, C. : Connes Henry andMalka, J.: Treatment of open fractures with a loss of osseous substance : examples from clinical cases. In Brocker, A.F. and Edwards, C.C. Editors, External fixation, the current state of the art, Baltimore, 1979, The Williams & Wilkins Co.

75. Vincent, A. : Hamada, K. : Rigbotte, A. and Gial-anella Joseph : Multiple pin fixation and immediate weight bearing. J.Bone Joint Surg. 51-A : 1241, 1969.

76. Whitney, W.D. ; (1962) : Atharva Veda-Samhita, Vol I-2, Varanasi.